NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4251

AN EXPERIMENTAL INVESTIGATION OF WAKE EFFECTS ON HYDRO-SKIS

By Ellis E. McBride and Lloyd J. Fisher

Langley Aeronautical Laboratory
Langley Field, Va.

Washington
May, 1958

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SUMMARY

An experimental investigation was made in Langley tank no. 2 to determine the effects of planing in a wake on the forces of a planing surface and to locate desirable positions in the wake with regard to the lift and lift-drag ratio of the planing surface. Two combinations of multiple hydro-skis were tested: two hydro-skis in tandem and three hydro-skis arranged with a single front hydro-ski and two rear hydro-skis. Drag, wetted area, and draft of the rear hydro-skis at selected loads were measured at various positions in the wake of the front hydro-ski and were compared with the planing forces of a single hydro-ski in undisturbed water at similar planing conditions.

The results of the investigation show that the rear hydro-ski in a tandem arrangement could have large increases in lift coefficient and small improvements in lift-drag ratio compared with a hydro-ski in undisturbed water over a limited speed range. The two trailing hydro-skis in a three-hydro-ski arrangement would tend to have losses in efficiency compared with hydro-skis in undisturbed water, but the losses could be prevented by carefully selecting the hydro-ski spacing.

INTRODUCTION

Quantities of data on many different shapes of surfaces planing in undisturbed water are available and work has been done on mapping the profile and transverse wave contours of the wake of these planing surfaces. Little has been done, however, to determine the effect of a wake forward of planing surfaces, except for the case of an afterbody planing in the wake of its forebody. Such information would be useful in the design of multiple hydro-ski configurations. An investigation was therefore made in Langley tank no. 2 to determine the effects of a wake on the forces of a trailing planing surface and to locate desirable positions in the wake with regard to lift and lift-drag ratio. Flat rectangular plates were used as the planing surfaces and two combinations of hydro-skis were investigated: a pair of hydro-skis in tandem and three hydro-skis with two rear hydro-skis following in the wake of a single forward hydro-ski. The data obtained in this investigation are presented in tabular form and as plots of the ratios of lift coefficient, lift-drag ratio, and draft measured in the wake to corresponding values at the same angle of attack, speed, and load in undisturbed water.

SYMBOLS

b	beam of planing surface, ft
C_L	lift coefficient based on wetted area, $\dfrac{L}{\frac{\rho}{2} SV^2}$
$\dfrac{C_{L,w}}{C_L}$	ratio of the lift coefficient measured in the wake to that measured in undisturbed water at similar planing conditions
C_V	speed coefficient, $\dfrac{V}{\sqrt{gb}}$
C_Δ	load coefficient or beam loading, $\dfrac{\Delta}{\rho g b^3}$
d	draft at trailing edge (measured vertically from undisturbed water surface), ft
$\dfrac{d_w}{d}$	ratio of the draft measured in the wake to that measured in undisturbed water at similar planing conditions
D	total drag of planing surface, lb
g	acceleration due to gravity, 32.2 ft/sec^2
l_m	mean wetted length, ft
L	total lift of planing surface, lb
L/D	lift-drag ratio

$\dfrac{(L/D)_w}{(L/D)}$	ratio of the lift-drag ratio measured in the wake to that measured in undisturbed water at similar planing conditions
S	wetted planing area, sq ft
V	carriage speed, fps
x	longitudinal spacing of hydro-skis, beams
y	center-line spacing between hydro-skis, beams
Δ	vertical load, lb ($\Delta = L$)
ϵ	effective downwash angle, $\alpha - \alpha'$, deg
ρ	mass density of tank water, 1.942 slug/cu ft
α	geometric (pre-set) angle of attack (measured between planing surface and undisturbed water surface), deg
α'	effective angle of attack (computed), deg

Subscript:

w	value measured in the wake

APPARATUS AND PROCEDURE

Description of Models

The planing surfaces used as models were flat rectangular plates of stainless steel 10 inches long, 2 inches wide, and 3/8 inch thick machined and ground smooth on all surfaces so that all corners and edges were sharp and square. The bottoms of the models were marked to facilitate reading of wetted lengths from underwater photographs.

Test Methods and Equipment

The tests were made with the models attached to the main towing carriage in Langley tank no. 2. Figure 1(a) shows the two hydro-skis in the tandem arrangement and figure 1(b) shows the three-hydro-ski arrangement installed on the towing carriage. No forces were measured on the front hydro-ski, since the only function of this surface was to provide a wake at the same load and pre-set angle of attack as the rear hydro-ski or hydro-skis. The hydro-skis were mounted so that they were free to rise but were fixed in all other degrees of freedom. The hydro-skis could be positioned at various distances apart, so that the relationship of the rear hydro-skis to the wake of the front hydro-ski could be changed.

A constant load was applied through the towing staffs so that the load on each hydro-ski was the same (the load on the two rear hydro-skis being assumed equally divided between them). The drag was measured by an electrical strain-gage beam and its deflection was read visually on a galvanometer. The tests were made without a wind screen. Tare runs were made with the rear hydro-skis removed and the force of the air and of the spray from the front hydro-ski impinging on the rear struts was measured. These tares are subtracted from the drag data presented. The draft was read visually from a scale by means of a pointer attached to the towing staff. Wetted area was measured from underwater photographs made with a 70-millimeter camera mounted in a waterproof box located on the bottom of the tank. The camera and high-speed flash lamps were set off by the action of the carriage interrupting a photo-electric beam. A similar camera was mounted on a boom attached to the towing carriage to take above-water profile pictures of the models being tested.

The accuracy of the various measurements is estimated to be as follows:

Load, lb	±0.01
Drag, lb	±0.02
Angle of attack, deg	±0.1
Draft, ft	±0.01
Mean wetted length, ft	±0.01
Speed, fps	±0.2

Tests were made at angles of attack of 6°, 12°, and 18° at loads of 4.0, 7.0, and 13.0 pounds per hydro-ski and at constant speeds from 15 to 55 feet per second. All the test speeds are above the critical wave speed of the tank (13.8 fps, limiting speed of transverse wave propagation). The rear hydro-skis were tested at locations of 5, 10, 15, and 19 beams aft of the front hydro-ski (measured trailing edge to trailing edge). In the three-hydro-ski arrangement the two rear hydro-skis were tested with center-line spacings of 3, 5, and 7 beams.

RESULTS AND DISCUSSION

General

In an analysis of the results of this investigation, it is important to consider the effect of the pertinent parameters on the contour of the wake. A sketch of the approximate shape of the wake of a flat planing surface is given in figure 2. At a given angle of attack and load coefficient an increase in speed coefficient decreases the draft and moves the roach aft but has little effect on the depth of the trough or the height and location of the side wave. At a given speed coefficient and load coefficient an increase in angle of attack has an effect similar to an increase in speed coefficient. At a given angle of attack and speed coefficient an increase in load coefficient increases the draft, moves the roach forward, and increases the depth of the trough and the height of and width between the side waves.

The lift coefficients, lift-drag ratios, and drafts measured in the wake are presented herein as ratios referred to the values in undisturbed water at the same angle of attack, speed, and load. The undisturbed-water values for C_L and L/D were taken from reference 1 and values for d, from reference 2. The effective angle of attack α' that would be necessary to produce the measured lift coefficients if the planing surface were running in undisturbed water at the same length-beam ratio at free-stream velocity has also been determined by using reference 1. The effective downwash angle ϵ for the test conditions was computed from the relation $\epsilon = \alpha - \alpha'$.

Two-Hydro-Ski Arrangement in Tandem

The experimental data for the two hydro-skis in tandem are presented in table I(a), and plots of the ratios of the lift coefficients, lift-drag ratios, and drafts as well as the effective downwash angles are presented in figure 3. The data are plotted as a function of the longitudinal spacing between the two hydro-skis measured in beams; speed coefficient and angle of attack are parameters. The forces tend to peak when the trailing hydro-ski is riding the up slope of the roach of the front hydro-ski. As the speed coefficient increases, the peak occurs at greater longitudinal spacings or is never reached in the range of locations tested. The ratio d_W/d increased rapidly with increasing speed at a constant load coefficient. When the load coefficient was increased and the speed further increased, this ratio was reduced because of the increased draft of the hydro-ski in undisturbed water. Some effects on the lift-drag ratio paralleling that on the lift coefficient and the downwash angle were noted.

The results obtained at all angles of attack of the tests were similar. The most interesting point was a lift coefficient in the wake at $\alpha = 12^{\circ}$ (fig. 3(b)) of 2.7 times that obtained in undisturbed water. Because of the higher speeds necessary to support the load at $\alpha = 6^{\circ}$, the roach was always located aft of the trailing hydro-ski. This position of the roach resulted in an increase in the lift coefficient as the trailing hydro-ski was moved aft. The most significant effect of angle of attack was the appreciable change in the lift-drag-ratio parameter obtained at $\alpha = 6^{\circ}$ (fig. 3(a)). At this angle of attack, the friction drag is a large part of the total drag; whereas, at high angles the friction drag may be considered almost a negligible part of the total. The hydro-ski, when operating at $\alpha = 6^{\circ}$ in a downwash, requires an increase in wetted area to support the load. This increase in wetted area causes an increase in friction drag and results in a decrease in the lift-drag-ratio parameter. The inverse is true when the surface is operating in an upwash.

Figure 4 shows underwater and side photographs of the trailing hydro-ski in the tandem arrangement operating in contrasting regions of the wake. The lower two photographs show the hydro-ski in a region where the lift coefficient is increased by the presence of the wake (upwash) and the upper two photographs show a region where the wake is detrimental (downwash).

No single position in the wake within the range tested was found where either the lift-drag ratio or the lift coefficient was increased over the entire speed and angle-of-attack range of the tests. Large increases in lift coefficient and small improvement in lift-drag ratio were obtained at some positions through a restricted speed range. The effect of speed can be seen in figure 5 (a cross plot from fig. 3), where speed coefficient C_V is the abscissa. For example assume a flat-bottom tandem hydro-ski installation to have hydro-skis with 3-foot beams spaced 15 beams apart, operating at a hump speed of about 50 knots ($C_V = 9$) and an angle of attack of 12°; then, the ratio of the lift coefficient in the wake to the lift coefficient in smooth water $\frac{C_{L,w}}{C_L}$ is seen to be 1.6. Just prior to hump speed a maximum $\frac{C_{L,w}}{C_L}$ of 2.7 was obtained; however, soon after the hump speed is reached the ratio $\frac{C_{L,w}}{C_L}$ is reduced to less than unity. This result indicates that a tandem arrangement might be more efficient over a critical speed range, such as in the region of the hump speed, than in undisturbed water. One of the hydro-skis could then be retracted (provided adequate longitudinal balance was available) for the remainder of the take-off run. The relatively large longitudinal hydro-ski spacing required for an efficient tandem arrangement, however, may limit the usefulness of this type of installation.

Three-Hydro-Ski Arrangement

For the three-hydro-ski arrangement, the side-wave contours in the wake were the significant regions to be considered, whereas the roach was the important part of the wake for the tandem hydro-ski arrangement. Angle of attack and speed were rather minor parameters for the three-hydro-ski arrangement, since the location and characteristics of the side-wave contours were only slightly affected by changes in angle of attack and speed. This result is in contrast to the large dependence of the roach on these parameters noted with the tandem arrangement. The data obtained with the three-hydro-ski arrangement are presented in table I(b) and figures 6 to 10. The plots are similar to those for the tandem arrangement except that an additional variable, the width between the center lines of the two rear hydro-skis, is added. With center-line spacings of 3 and 5 beams, an improvement in lift coefficient and lift-drag ratio because of the presence of the wake could usually be obtained only at the shorter longitudinal spacing (figs. 6 to 8). As the longitudinal spacing increased, in general, the lift coefficient and the lift-drag ratio decreased because the hydro-skis were operating in a downwash. Part of the change in lift-drag ratio was probably due to an increase in drag caused by spray from the front hydro-ski striking the leading edge of the two rear hydro-skis, as can be seen in the side photographs of figure 9. This spray drag was not measured and subtracted as a tare. The underwater photographs of figure 9 show the relationship of the hydro-skis to the wake and some rather interesting wetted areas caused by the contour of the wave on which the skis were planing. When the center-line spacing was 7 beams, the two rear hydro-skis were far enough outboard to be almost clear of the wake and only small changes in the data were measured. The three-hydro-ski arrangement with a center-line spacing of 7 beams was not tested at $\alpha = 6^{\circ}$, since preliminary tests had indicated that at this condition, the effect of the wake would be negligible.

At low speed coefficients and large longitudinal spacings the lift sometimes became insufficient to support the model as a result of unfavorable downwash, and the hydro-ski submerged; consequently, corresponding points are missing in figures 6(a), 7(a), 7(b), and 8(a). At $\alpha = 12^{\circ}$ an instability developed at high speeds for longitudinal spacings less than 15 beams, when the hydro-skis got too close to the side wave. The instability was such that data could not be measured, so that the corresponding data points are missing in figures 7(a) and 7(b).

If it were practical to locate the hydro-skis far enough aft, the downwash usually encountered with the three-hydro-ski arrangement might be avoided but within the range of the tests, moving the hydro-skis aft generally decreased the lift coefficient, the lift-drag ratio, and the effective angle of attack. Increasing the center-line spacing between the rear hydro-skis reduced the effect of the wake. The effect of hydro-ski spacing can be seen in figure 10 (a cross plot from figures 6, 7, and 8). The three-hydro-ski arrangement frequently experienced losses in efficiency compared with hydro-skis in undisturbed water but indications were that the losses might be prevented by carefully selecting the hydro-ski spacing.

CONCLUSIONS

The results of the investigation of hydro-skis in a wake indicated that:

1. The rear hydro-ski in a tandem arrangement could have large increases in lift coefficient and small improvements in lift-drag ratio compared with hydro-skis in undisturbed water over a limited speed range.

2. The trailing hydro-skis in a three-hydro-ski arrangement would tend to experience losses in efficiency compared with hydro-skis in undisturbed water, but the losses could apparently be prevented by carefully selecting the hydro-ski spacing.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 17, 1958.

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TABLE I

EXPERIMENTAL DATA FOR FLAT-PLATE HYDRO-SKIS MEASURED IN A WAKE

[b = 0.167 ft]

(a) Tandem hydro-ski arrangement

α, deg	Spacing, x, beams	C_V	C_Δ	C_L	L, lb	D, lb	l_m/b	d/b
6	5	15.13	13.85	0.038	4	0.98	3.2	1.6
6	5	16.20	13.85	.035	4	.98	3.0	1.5
6	5	17.30	13.85	.046	4	.92	2.0	1.0
6	10	12.96	13.85	.038	4	.92	4.4	2.2
6	10	14.05	13.85	.044	4	.91	3.2	1.6
6	10	15.13	13.85	.053	4	.91	2.3	1.2
6	10	16.20	13.85	.053	4	.86	2.0	1.0
6	10	17.30	13.85	.062	4	.86	1.5	.8
6	15	10.80	13.85	.055	4	.83	4.3	2.2
6	15	11.90	13.85	.059	4	.83	3.3	1.7
6	15	12.96	13.85	.057	4	.83	2.9	1.5
6	15	14.05	13.85	.056	4	.83	2.5	1.3
6	15	15.13	13.85	.061	4	.80	2.0	1.0
6	15	16.20	13.85	.071	4	.77	1.5	.8
6	15	17.30	13.85	.077	4	.77	1.2	.6
6	15	23.80	45.00	.033	13	3.18	4.9	2.5
6	19	9.73	13.85	.086	4	.61	3.4	1.7
6	19	10.80	13.85	.095	4	.65	2.5	1.3
6	19	11.90	13.85	.087	4	.71	2.3	1.1
6	19	12.96	13.85	.075	4	.74	2.2	1.1
6	19	14.05	13.85	.070	4	.77	2.0	1.0
6	19	15.13	13.85	.097	4	.74	1.3	.6
6	19	16.20	13.85	.117	4	.77	.9	.5
6	19	17.30	13.85	.124	4	.77	.8	.4
6	19	17.30	24.20	.048	7	1.53	3.4	1.7
6	19	17.30	24.20	.046	7	1.53	3.5	1.8
6	19	23.80	45.00	.039	13	2.89	4.1	2.0
12	5	7.57	13.85	.098	4	.94	5.0	2.5
12	5	8.65	13.85	.093	4	1.00	4.0	2.0
12	5	9.73	13.85	.105	4	1.00	2.8	1.4
12	5	10.80	13.85	.129	4	1.00	1.9	.9
12	5	11.90	13.85	.157	4	1.00	1.3	.6
12	5	17.30	45.00	.076	13	3.25	4.0	2.0
12	5	17.30	45.00	.074	13	3.25	4.1	2.1
12	10	6.48	13.85	.180	4	.94	3.7	1.8
12	10	7.57	13.85	.176	4	.91	2.8	1.4
12	10	8.65	13.85	.165	4	.94	2.3	1.1
12	10	9.73	13.85	.178	4	.94	1.7	.8
12	10	10.80	13.85	.183	4	.94	1.3	.7
12	10	17.30	45.00	.104	13	3.30	2.9	1.5
12	10	17.30	45.00	.108	13	3.30	2.8	1.4

TABLE I.- Continued

EXPERIMENTAL DATA FOR FLAT-PLATE HYDRO-SKIS MEASURED IN A WAKE

[b = 0.167 ft]

(a) Tandem hydro-ski arrangement - Concluded

α, deg	Spacing, x, beams	C_V	C_Δ	C_L	L, lb	D, lb	l_m/b	d/b
12	15	6.48	13.85	0.240	4	0.94	2.8	1.4
12	15	7.57	13.85	.323	4	.89	1.5	.8
12	15	8.65	13.85	.265	4	.89	1.4	.7
12	15	9.73	13.85	.244	4	.91	1.2	.6
12	15	10.80	13.85	.218	4	.91	1.1	.6
12	15	17.30	45.00	.126	13	3.25	2.4	1.2
12	15	17.30	45.00	.128	13	3.25	2.4	1.2
12	19	6.48	13.85	.169	4	1.06	3.9	2.0
12	19	7.57	13.85	.226	4	.94	2.2	1.1
12	19	8.65	13.85	.337	4	.94	1.1	.6
12	19	9.73	13.85	.309	4	.83	1.0	.5
12	19	10.80	13.85	.297	4	.94	.8	.4
12	19	11.90	13.85	.327	4	.94	.6	.3
12	19	17.30	45.00	.151	13	3.25	2.0	1.0
18	5	6.48	13.85	.216	4	1.30	3.1	1.5
18	5	7.57	13.85	.216	4	1.30	2.3	1.1
18	5	8.65	13.85	.256	4	1.30	1.5	.7
18	5	9.73	13.85	.279	4	1.28	1.1	.5
18	5	10.80	13.85	.339	4	1.26	.7	.4
18	5	12.96	45.00	.160	13	4.48	3.4	1.7
18	5	12.96	45.00	.163	13	4.48	3.3	1.7
18	10	6.48	13.85	.330	4	1.24	2.0	1.0
18	10	7.57	13.85	.324	4	1.28	1.5	.8
18	10	8.65	13.85	.353	4	1.24	1.1	.5
18	10	9.73	13.85	.392	4	1.28	.8	.4
18	10	10.80	13.85	.452	4	1.30	.5	.3
18	10	12.96	45.00	.210	13	4.31	2.6	1.3
18	10	12.96	45.00	.214	13	4.31	2.5	1.3
18	15	6.48	13.85	.412	4	1.32	1.6	.8
18	15	7.57	13.85	.441	4	1.24	1.1	.6
18	15	8.65	13.85	.371	4	1.30	1.0	.5
18	15	9.73	13.85	.452	4	1.26	.7	.3
18	15	10.80	13.85	.528	4	1.30	.5	.2
18	15	12.96	45.00	.250	13	4.24	2.2	1.1
18	15	12.96	45.00	.243	13	4.24	2.2	1.1
18	19	6.48	13.85	.315	4	1.36	2.1	1.1
18	19	7.57	13.85	.404	4	1.30	1.2	.6
18	19	8.65	13.85	.413	4	1.30	.9	.5
18	19	9.73	13.85	.452	4	1.26	.7	.3
18	19	10.80	13.85	.339	4	1.30	.7	.4
18	19	12.96	45.00	.275	13	4.13	2.0	1.0
18	19	12.96	45.00	.282	13	4.13	1.9	1.0

TABLE I.- Continued

EXPERIMENTAL DATA FOR FLAT-PLATE HYDRO-SKIS MEASURED IN A WAKE

[b = 0.167 ft]

(b) Three-hydro-ski arrangement

α, deg	Spacing		C_V	C_Δ	C_L	L, lb	D, lb	l_m/b	d/b
	x, beams	y, beams							
6	5	3	11.90	13.85	0.052	4	2.01	3.8	1.9
6	5	3	12.96	13.85	.059	4	2.07	2.8	1.4
6	5	3	14.05	13.85	.072	4	2.07	2.0	1.0
6	5	3	15.13	13.85	.093	4	2.12	1.3	.7
6	5	3	16.20	13.85	.085	4	2.12	1.3	.7
6	5	3	17.30	13.85	.093	4	2.18	1.0	.5
6	5	3	17.30	24.20	.065	7	3.48	2.5	1.3
6	10	3	14.05	13.85	.040	4	3.72	3.5	1.8
6	10	3	15.13	13.85	.054	4	3.42	2.3	1.1
6	10	3	16.30	13.85	.060	4	3.19	1.8	.9
6	10	3	17.30	13.85	.074	4	2.83	1.3	.7
6	15	3	16.20	13.85	.035	4	6.25	3.0	1.5
6	15	3	17.30	13.85	.037	4	5.66	2.5	1.3
6	19	3	16.20	13.85	.023	4	7.00	4.5	2.3
6	19	3	17.30	13.85	.029	4	6.00	3.3	1.7
6	5	5	11.90	13.85	.055	4	1.96	3.6	1.8
6	5	5	12.96	13.85	.066	4	1.85	2.5	1.3
6	5	5	14.05	13.85	.083	4	1.85	1.7	.9
6	5	5	15.13	13.85	.097	4	1.85	1.3	.6
6	5	5	16.20	13.85	.101	4	1.96	1.1	.5
6	5	5	17.30	24.20	.066	7	3.10	2.5	1.2
6	5	5	17.30	24.20	.064	7	3.10	2.6	1.3
6	5	5	23.80	45.00	.071	13	5.68	2.3	1.1
6	5	5	23.80	45.00	.071	13	5.68	2.3	1.1
6	10	5	11.90	13.85	.045	4	1.94	4.4	2.2
6	10	5	12.96	13.85	.053	4	2.00	3.1	1.5
6	10	5	14.05	13.85	.070	4	1.88	2.0	1.0
6	10	5	15.13	13.85	.093	4	1.94	1.3	.7
6	10	5	16.20	13.85	.117	4	1.94	.9	.5
6	10	5	17.30	24.20	.053	7	3.45	3.1	1.5
6	10	5	17.30	24.20	.053	7	3.45	3.1	1.5
6	10	5	23.80	45.00	.056	13	5.92	2.9	1.4
6	10	5	23.80	45.00	.055	13	6.03	2.9	1.5
6	15	5	12.96	13.85	.043	4	2.12	3.9	1.9
6	15	5	14.05	13.85	.053	4	2.05	2.7	1.3
6	15	5	15.13	13.85	.069	4	1.94	1.8	.9
6	15	5	17.30	13.85	.093	4	2.05	1.0	.5
6	15	5	17.30	24.20	.047	7	3.69	3.5	1.7
6	15	5	17.30	24.20	.049	7	3.69	3.4	1.7
6	15	5	23.80	45.00	.051	13	6.15	3.2	1.6
6	19	5	12.96	13.85	.040	4	2.29	4.2	2.1
6	19	5	14.05	13.85	.050	4	2.17	2.8	1.4
6	19	5	15.13	13.85	.064	4	2.12	1.9	1.0
6	19	5	16.20	13.85	.084	4	2.12	1.3	.6
6	19	5	17.30	13.85	.116	4	2.12	.8	.4
6	19	5	17.30	24.20	.042	7	3.99	3.9	2.0
6	19	5	17.30	24.20	.043	7	3.99	3.8	1.9
6	19	5	23.80	45.00	.046	13	6.55	3.5	1.7
6	19	5	23.80	45.00	.046	13	6.50	3.5	1.7

TABLE I.- Continued

EXPERIMENTAL DATA FOR FLAT-PLATE HYDRO-SKIS MEASURED IN A WAKE

[b = 0.167 ft]

(b) Three-hydro-ski arrangement - Continued

α, deg	Spacing x, beams	Spacing y, beams	C_V	C_Δ	C_L	L, lb	D, lb	l_m/b	d/b
12	5	3	7.57	13.85	0.102	4	3.18	4.8	2.4
12	5	3	8.65	13.85	.128	4	2.42	2.9	1.5
12	5	3	9.73	13.85	.168	4	2.48	1.8	.9
12	5	3	10.80	13.85	.216	4	2.48	1.1	.6
12	5	3	11.90	13.85	.218	4	2.60	.9	.5
12	5	3	17.30	45.00	.188	13	7.31	1.6	.8
12	5	3	17.30	45.00	.168	13	7.31	1.8	.9
12	10	3	9.73	13.85	.082	4	3.77	3.6	1.8
12	10	3	10.80	13.85	.119	4	3.30	2.0	1.0
12	10	3	11.90	13.85	.157	4	3.18	1.3	.6
12	10	3	17.30	45.00	.121	13	7.31	2.5	1.3
12	15	3	10.80	13.85	.073	4	4.48	3.3	1.6
12	15	3	11.90	13.85	.084	4	4.13	2.4	1.2
12	15	3	12.96	13.85	.110	4	3.83	1.5	.8
12	19	3	10.80	13.85	.073	4	4.60	3.3	1.6
12	19	3	11.90	13.85	.079	4	4.48	2.5	1.3
12	19	3	12.96	13.85	.079	4	4.36	2.1	1.1
12	5	5	7.57	13.85	.123	4	2.08	4.0	2.0
12	5	5	8.65	13.85	.149	4	2.08	2.5	1.3
12	5	5	9.73	13.85	.183	4	2.08	1.6	.8
12	5	5	10.80	13.85	.226	4	2.20	1.1	.5
12	5	5	17.30	45.00	.201	13	6.50	1.5	.8
12	5	5	17.30	45.00	.194	13	6.43	1.6	.8
12	10	5	7.57	13.85	.102	4	2.32	4.8	2.4
12	10	5	8.65	13.85	.116	4	2.25	3.2	1.6
12	10	5	9.73	13.85	.147	4	2.26	2.0	1.0
12	10	5	10.80	13.85	.183	4	2.26	1.3	.7
12	10	5	17.30	45.00	.163	13	7.07	1.9	.9
12	12.5	5	17.30	45.00	.144	13	7.20	2.1	1.1
12	12.5	5	17.30	45.00	.147	13	7.07	2.1	1.0
12	15	5	8.65	13.85	.094	4	2.44	3.9	2.0
12	15	5	9.73	13.85	.115	4	2.50	2.5	1.3
12	15	5	10.80	13.85	.153	4	2.50	1.5	.8
12	15	5	11.90	13.85	.206	4	2.55	.9	.5
12	15	5	17.30	45.00	.131	13	7.43	2.3	1.2
12	15	5	17.30	45.00	.137	13	7.37	2.2	1.1
12	19	5	8.65	13.85	.085	4	3.30	4.3	2.2
12	19	5	9.73	13.85	.103	4	3.07	2.8	1.4
12	19	5	10.80	13.85	.125	4	2.78	1.9	1.0
12	19	5	11.90	13.85	.196	4	2.67	1.0	.5
12	19	5	17.30	45.00	.101	13	7.65	3.0	1.5

TABLE I.- Continued

EXPERIMENTAL DATA FOR FLAT-PLATE HYDRO-SKIS MEASURED IN A WAKE

[b = 0.167 ft]

(b) Three-hydro-ski arrangement - Continued

α, deg	Spacing		C_V	C_Δ	C_L	L, lb	D, lb	l_m/b	d/b
	x, beams	y, beams							
12	5	7	7.57	13.85	0.128	4	2.20	3.8	1.9
12	5	7	8.65	13.85	.155	4	2.20	2.4	1.2
12	5	7	9.73	13.85	.178	4	2.30	1.6	.8
12	5	7	10.80	13.85	.206	4	2.30	1.1	.6
12	5	7	11.90	13.85	.246	4	2.30	.8	.4
12	5	7	17.30	45.00	.189	13	6.72	1.6	.8
12	10	7	7.57	13.85	.112	4	2.24	4.3	2.2
12	10	7	8.65	13.85	.143	4	2.30	2.6	1.3
12	10	7	9.73	13.85	.173	4	2.24	1.7	.9
12	10	7	10.80	13.85	.206	4	2.30	1.1	.6
12	10	7	11.90	13.85	.231	4	2.30	.8	.4
12	10	7	17.30	45.00	.183	13	6.85	1.6	.8
12	15	7	7.57	13.85	.108	4	2.24	4.5	2.3
12	15	7	8.65	13.85	.138	4	2.24	2.7	1.4
12	15	7	9.73	13.85	.159	4	2.30	1.8	.9
12	15	7	10.80	13.85	.198	4	2.24	1.2	.6
12	15	7	17.30	45.00	.183	13	7.44	1.6	.8
12	15	7	17.30	45.00	.183	13	7.55	1.6	.8
12	19	7	7.57	13.85	.103	4	2.24	4.7	2.4
12	19	7	8.65	13.85	.124	4	2.30	3.0	1.5
12	19	7	9.73	13.85	.163	4	2.36	1.8	.9
12	19	7	10.80	13.85	.198	4	2.36	1.2	.6
12	19	7	11.90	13.85	.246	4	2.42	.8	.4
12	19	7	17.30	45.00	.168	13	8.38	1.8	.9
12	19	7	17.30	45.00	.178	13	8.19	1.7	.9
18	5	3	6.48	13.85	.178	4	3.12	3.7	1.9
18	5	3	7.57	13.85	.231	4	3.07	2.1	1.1
18	5	3	8.65	13.85	.337	4	3.18	1.1	.6
18	5	3	9.73	13.85	.488	4	3.30	.6	.3
18	5	3	12.96	45.00	.256	13	9.77	2.1	1.1
18	5	3	12.96	45.00	.256	13	9.65	2.1	1.1
18	10	3	7.57	13.85	.139	4	4.01	3.5	1.8
18	10	3	8.65	13.85	.124	4	3.66	3.0	1.5
18	10	3	9.73	13.85	.237	4	3.60	1.3	.6
18	10	3	12.96	45.00	.158	13	15.20	3.4	1.7
18	15	3	7.57	13.85	.149	4	4.13	3.3	1.6
18	15	3	8.65	13.85	.149	4	4.36	2.5	1.3
18	15	3	9.73	13.85	.130	4	4.13	2.3	1.1
18	19	3	7.57	13.85	.202	4	3.30	2.4	1.2
18	19	3	8.65	13.85	.165	4	3.60	2.3	1.1
18	19	3	9.73	13.85	.154	4	3.89	1.9	1.0

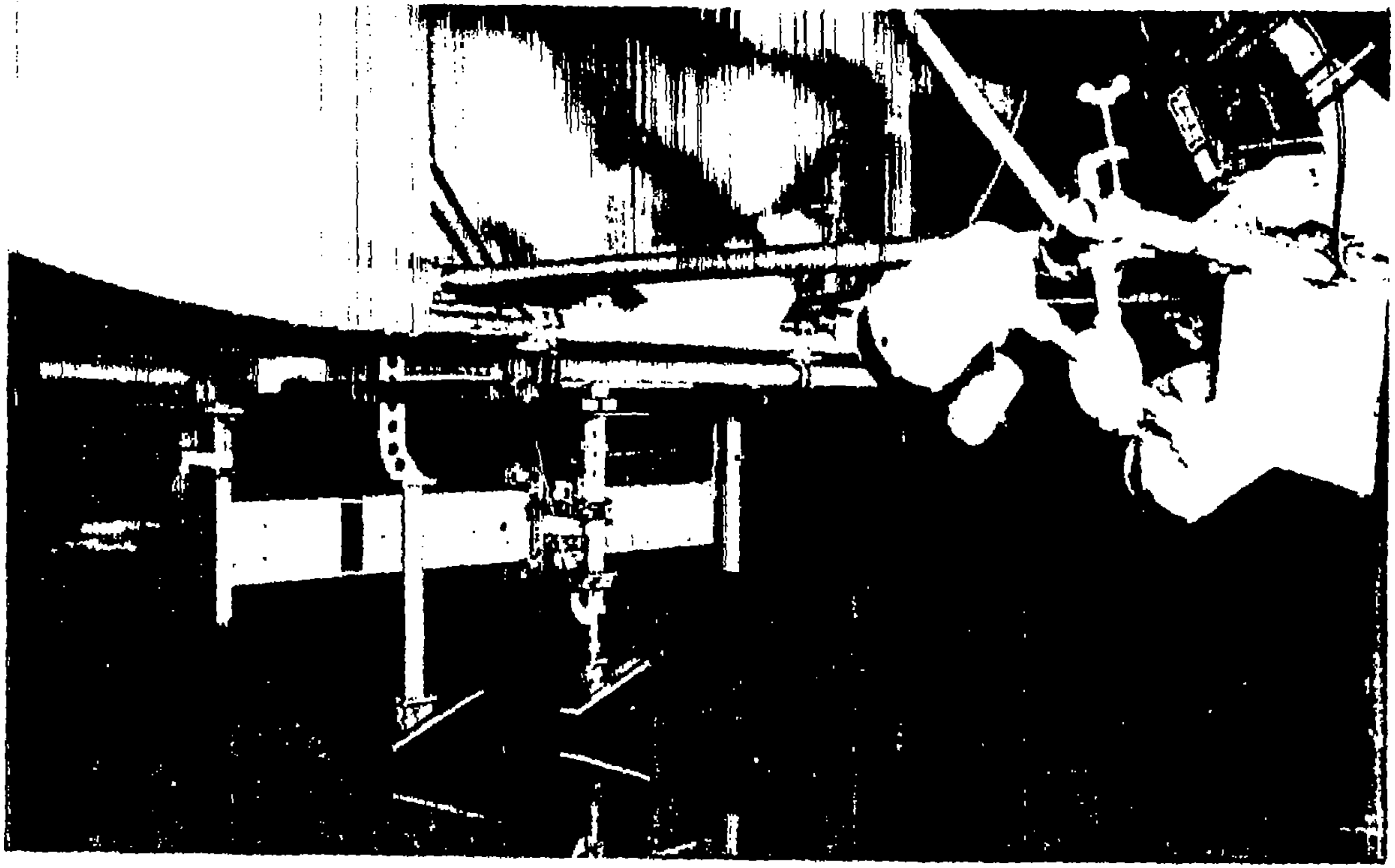
TABLE I.- Concluded

EXPERIMENTAL DATA FOR FLAT-PLATE HYDRO-SKIS MEASURED IN A WAKE

[b = 0.167 ft]

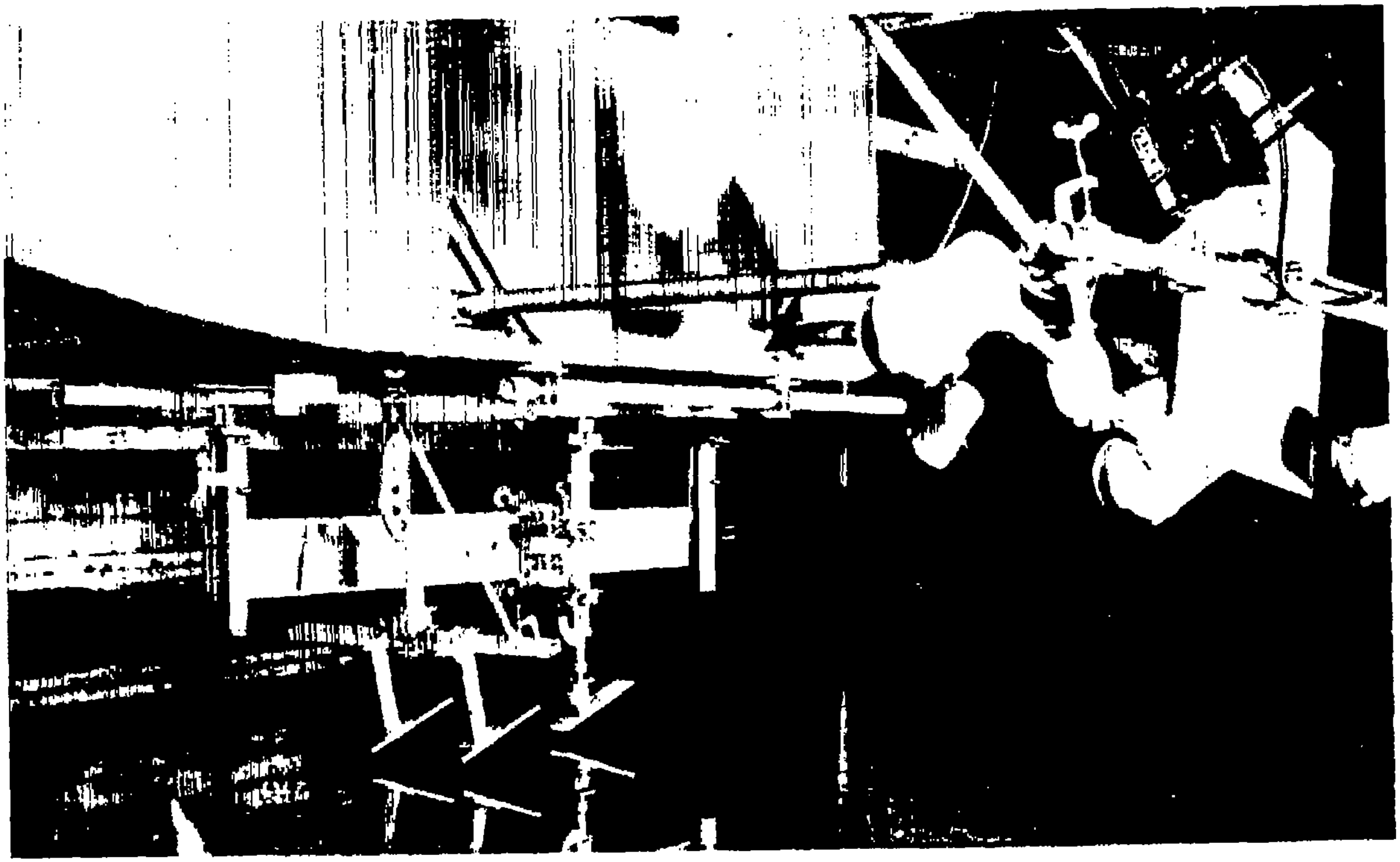
(b) Three-hydro-ski arrangement - Concluded

α, deg	Spacing		C_V	C_Δ	C_L	L, lb	D, lb	l_m/b	d/b
	x, beams	y, beams							
18	5	5	6.48	13.85	0.213	4	2.94	3.1	1.6
18	5	5	7.57	13.85	.262	4	2.94	1.9	.9
18	5	5	8.65	13.85	.337	4	2.94	1.1	.6
18	5	5	9.73	13.85	.391	4	2.94	.8	.4
18	5	5	12.96	45.00	.290	13	9.43	1.9	.9
18	10	5	6.48	13.85	.167	4	3.29	4.0	2.0
18	10	5	7.57	13.85	.206	4	3.23	2.4	1.2
18	10	5	8.65	13.85	.256	4	3.29	1.5	.7
18	10	5	9.73	13.85	.325	4	3.23	.9	.5
18	10	5	12.96	45.00	.238	13	10.61	2.3	1.1
18	10	5	12.96	45.00	.238	13	10.49	2.3	1.1
18	15	5	6.48	13.85	.142	4	4.11	4.7	2.3
18	15	5	7.57	13.85	.143	4	3.99	3.4	1.7
18	15	5	8.65	13.85	.225	4	3.99	1.7	.8
18	15	5	9.73	13.85	.254	4	3.88	1.2	.6
18	19	5	6.48	13.85	.142	4	3.70	4.7	2.3
18	19	5	7.57	13.85	.122	4	4.11	4.0	2.0
18	19	5	8.65	13.85	.185	4	4.29	2.0	1.0
18	19	5	9.73	13.85	.266	4	4.41	1.1	.6
18	19	5	12.96	45.00	.134	13	13.20	4.0	2.0
18	19	5	12.96	45.00	.134	13	15.72	4.0	2.0
18	5	7	6.48	13.85	.213	4	2.95	3.1	1.6
18	5	7	7.57	13.85	.262	4	2.95	1.9	.9
18	5	7	8.65	13.85	.322	4	2.95	1.2	.6
18	5	7	9.73	13.85	.367	4	3.01	.8	.4
18	5	7	12.96	45.00	.262	13	9.18	2.1	1.0
18	10	7	6.48	13.85	.194	4	3.01	3.4	1.7
18	10	7	7.57	13.85	.242	4	3.01	2.0	1.0
18	10	7	8.65	13.85	.309	4	3.01	1.2	.6
18	10	7	9.73	13.85	.346	4	3.07	.9	.4
18	10	7	12.96	45.00	.268	13	9.78	2.0	1.0
18	15	7	6.48	13.85	.186	4	3.07	3.6	1.8
18	15	7	7.57	13.85	.237	4	3.12	2.1	1.0
18	15	7	8.65	13.85	.297	4	3.18	1.3	.6
18	15	7	9.73	13.85	.335	4	3.24	.9	.4
18	15	7	12.96	45.00	.256	13	10.95	2.1	1.1
18	15	7	12.96	45.00	.250	13	10.95	2.2	1.1
18	19	7	6.48	13.85	.176	4	3.18	3.8	1.9
18	19	7	8.65	13.85	.286	4	3.24	1.3	.7
18	19	7	9.73	13.85	.345	4	3.36	.9	.4
18	19	7	12.96	45.00	.223	13	11.90	2.4	1.2
18	19	7	12.96	45.00	.223	13	11.90	2.4	1.2



(a) Tandem hydro-ski arrangement. L-58-126

Figure 1.- Photographs of models attached to the towing carriage.



(b) Three-hydro-ski arrangement. L-58-127

Figure 1.- Concluded.

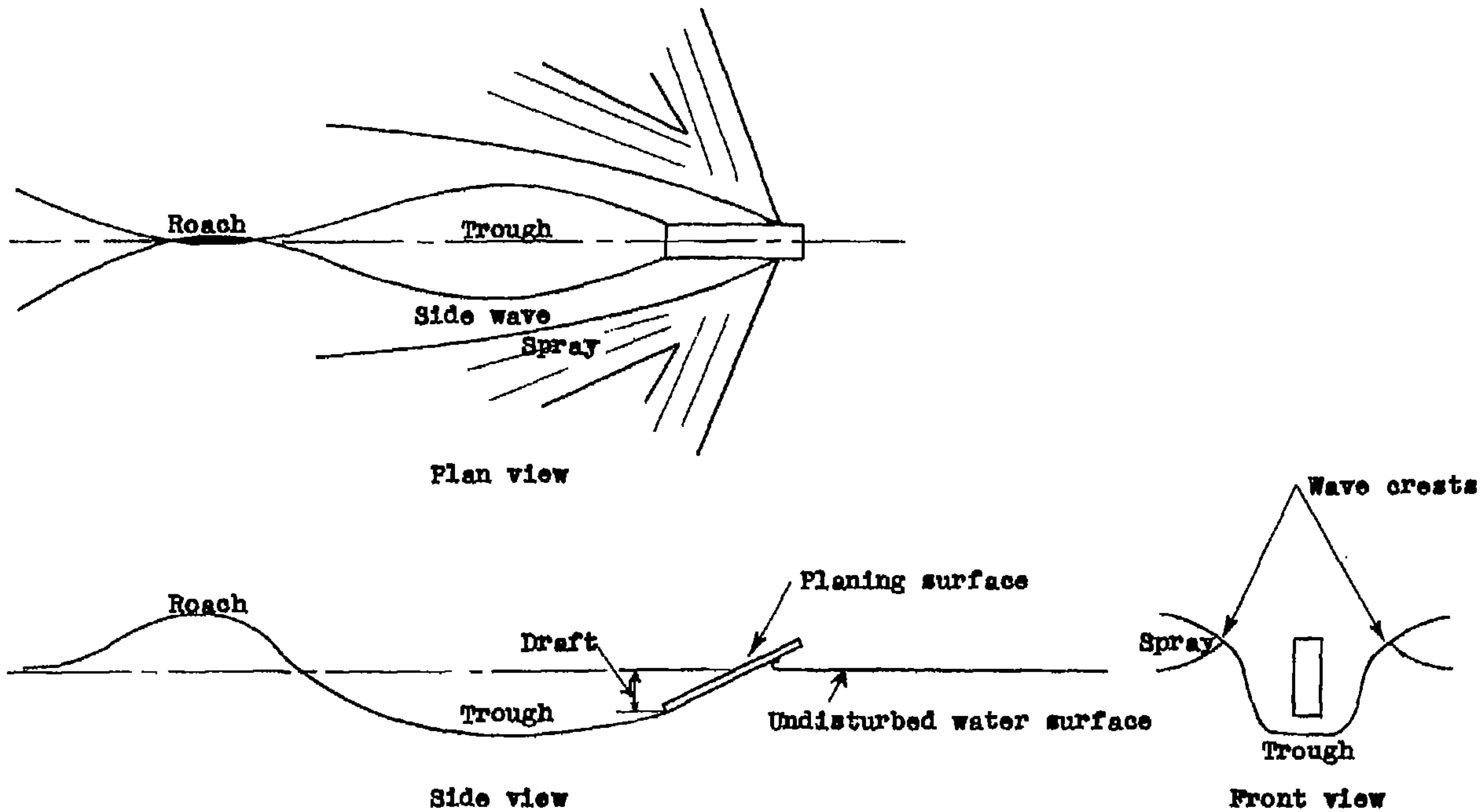
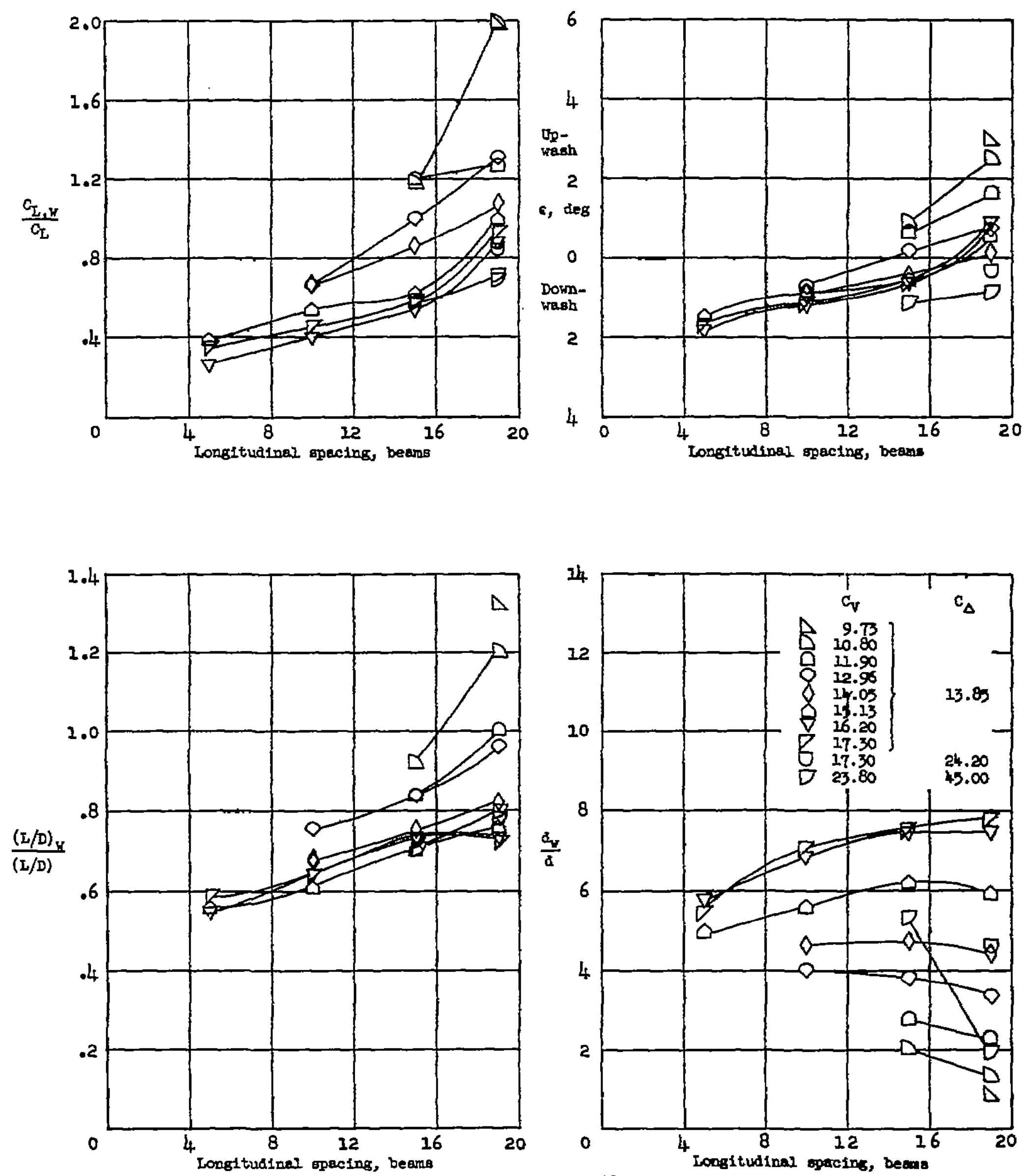
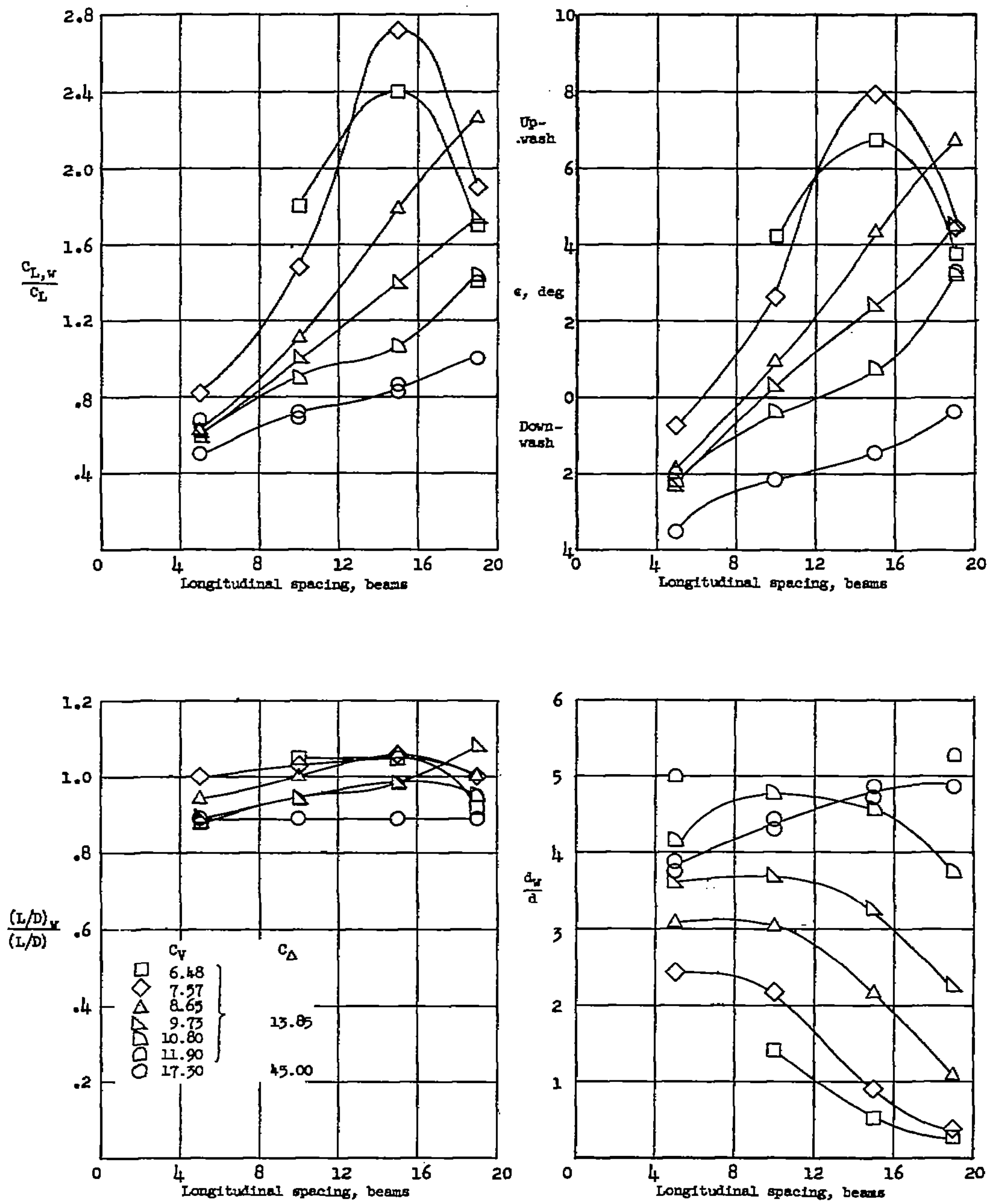


Figure 2.- Sketch of the approximate shape of the wake of a flat rectangular planing surface.



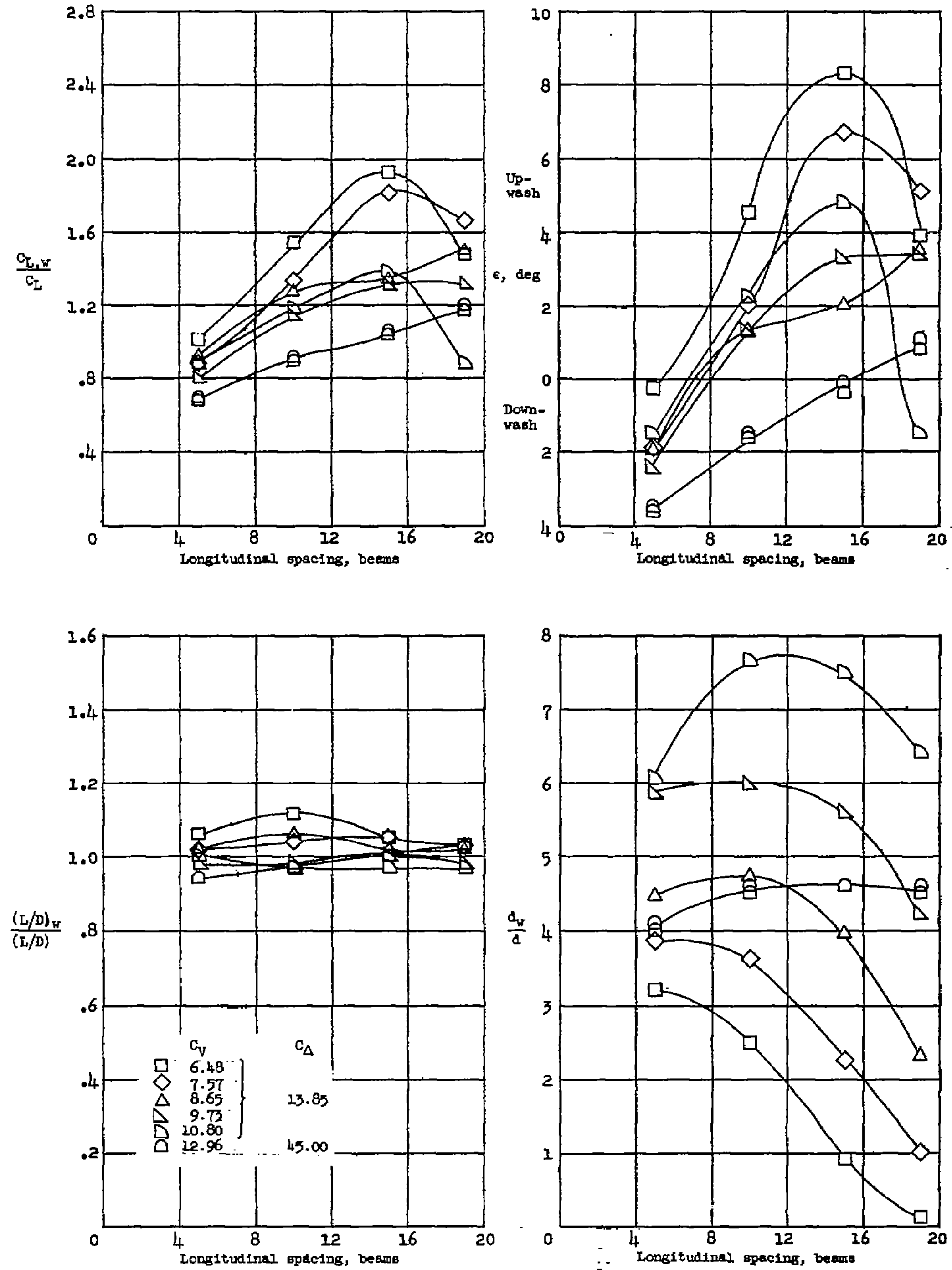
(a) $\alpha = 6^\circ$.

Figure 3.- Data obtained with the tandem hydro-ski arrangement.



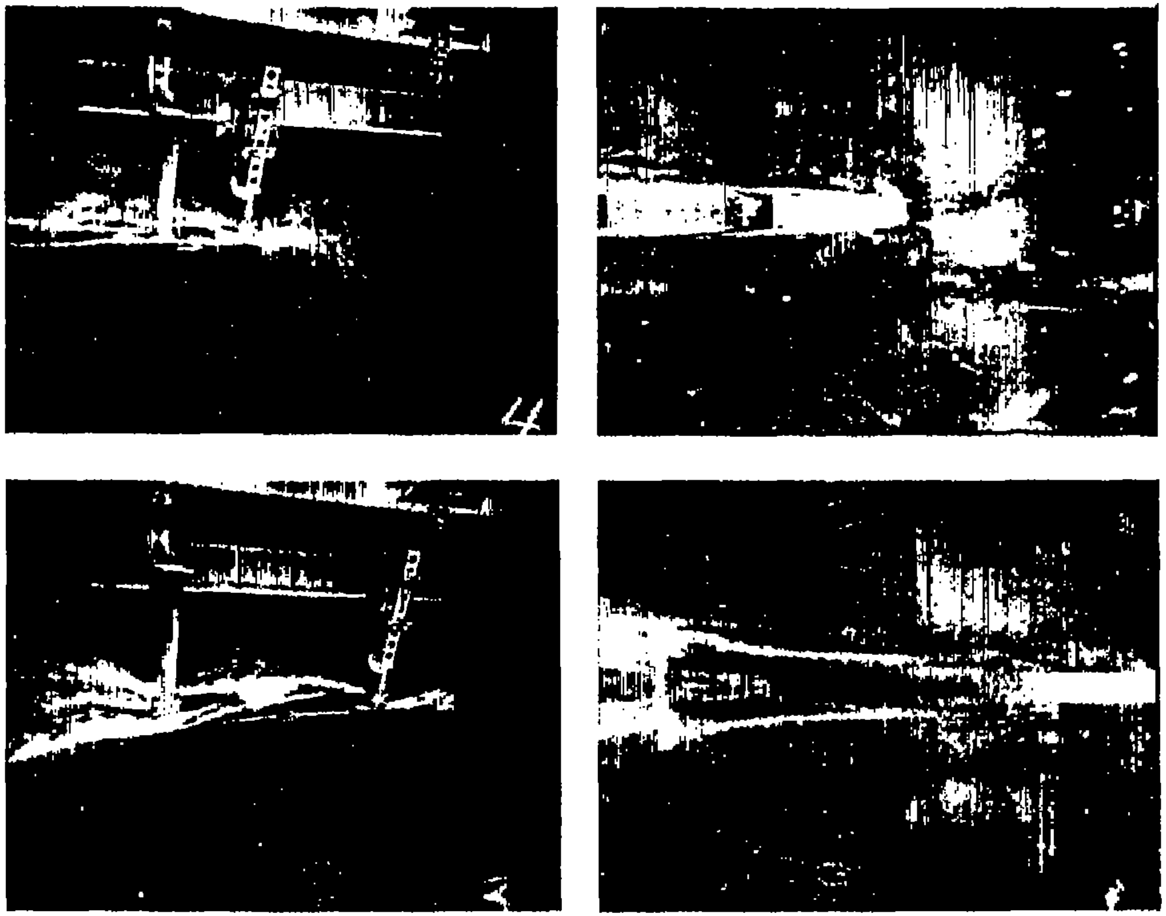
(b) $\alpha = 12^\circ$.

Figure 3.- Continued.



(c) $\alpha = 18^{\circ}$.

Figure 3.- Concluded.



Longitudinal spacing = 5 beams;

$\frac{C_{L,w}}{C_L} = 0.82;$

$\frac{(L/D)_w}{(L/D)} = 1.00.$

Longitudinal spacing = 15 beams;

$\frac{C_{L,w}}{C_L} = 2.7;$

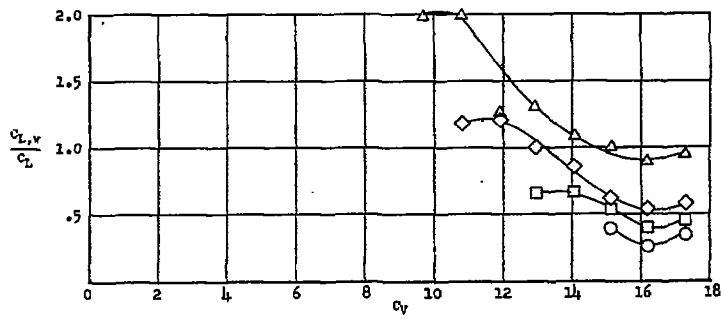
$\frac{(L/D)_w}{(L/D)} = 1.06.$

Side photographs

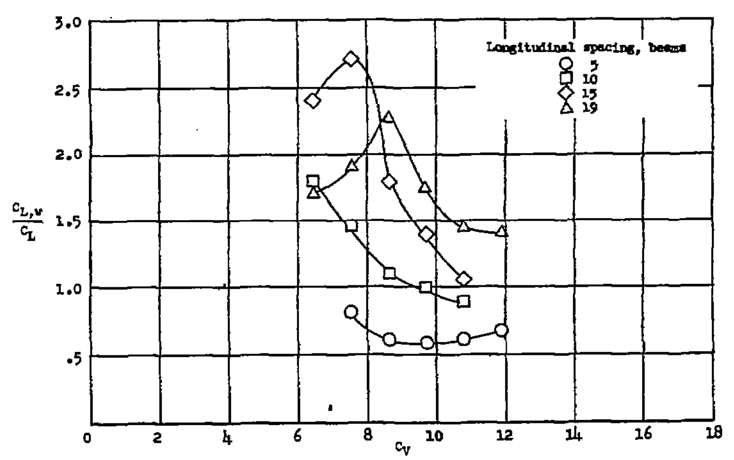
Underwater photographs

L-58-128

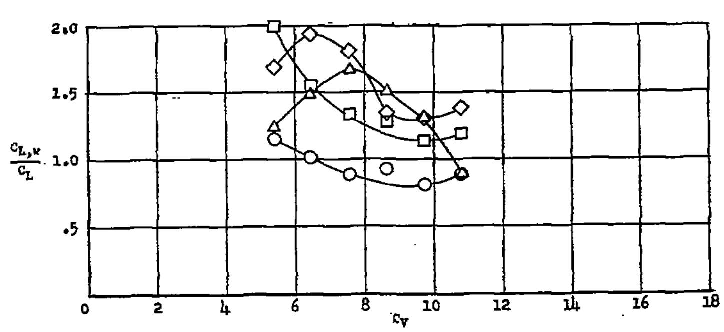
Figure 4.- Sample photographs of the tandem hydro-ski arrangement at $\alpha = 12^{\circ}$. $C_{\Delta} = 13.85$; $C_V = 7.57$.



(a) $\alpha = 6^{\circ}$.

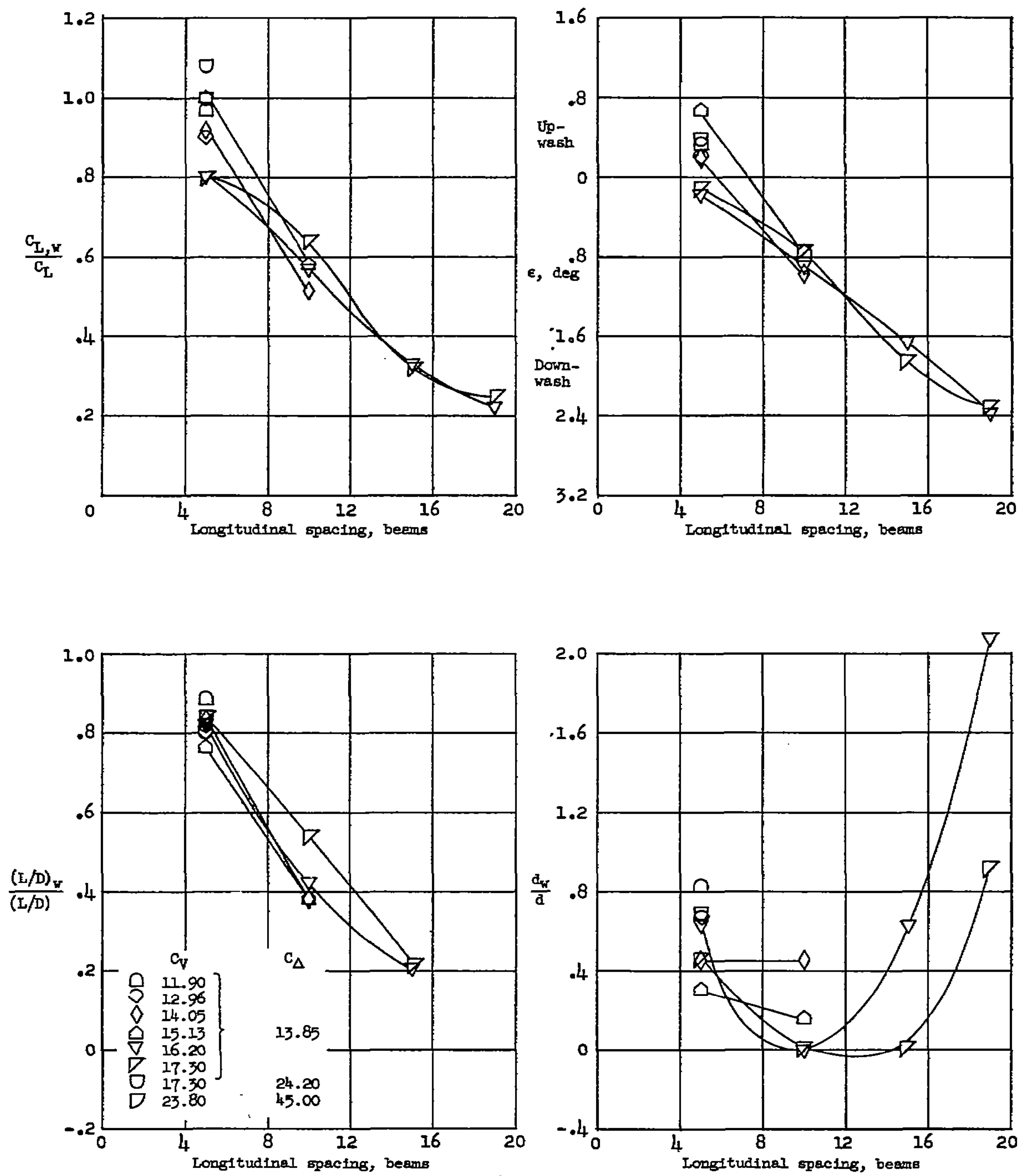


(b) $\alpha = 12^{\circ}$.



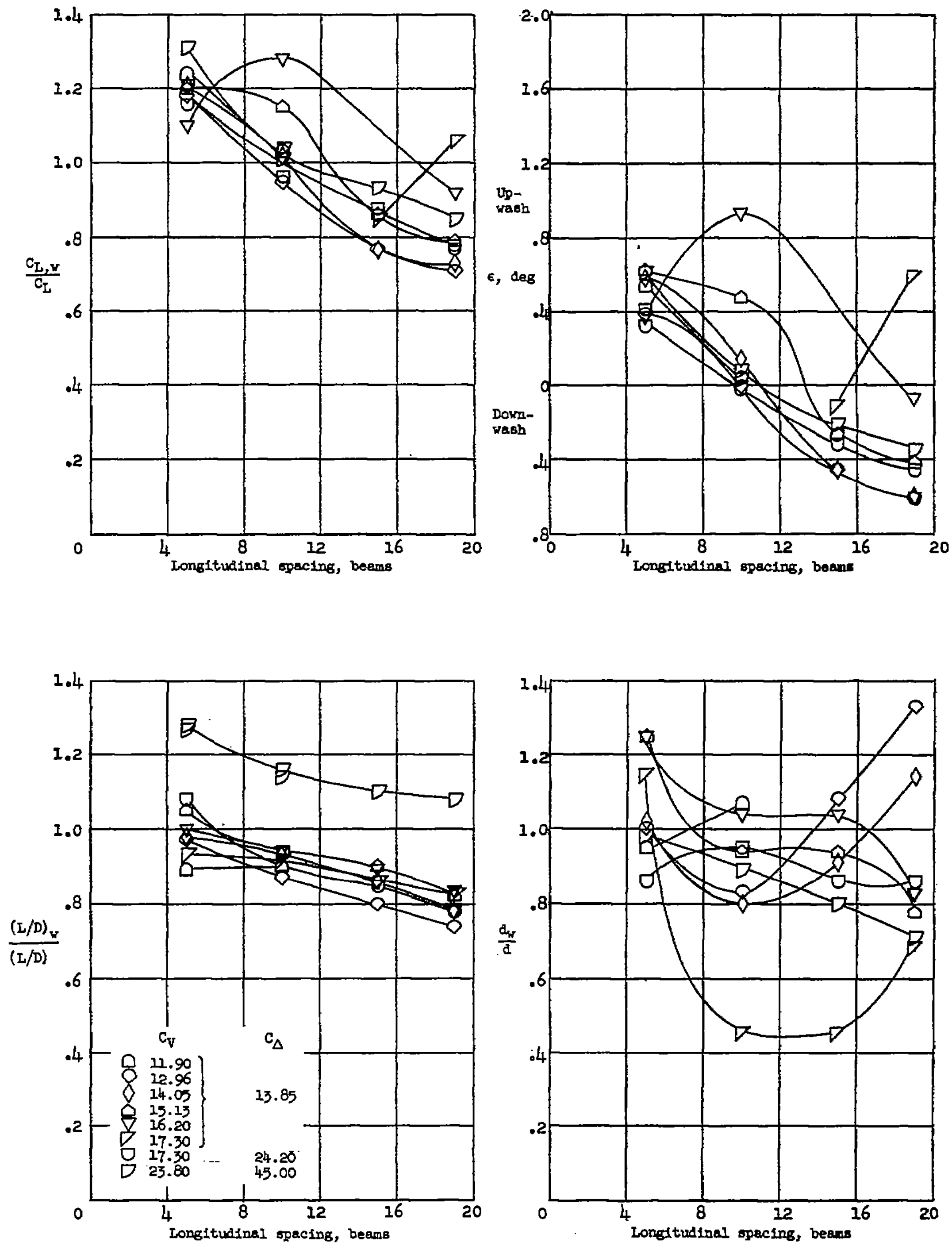
(c) $\alpha = 18^{\circ}$.

Figure 5.- Effect of speed on trailing hydro-ski in tandem arrangement. $C_{\Delta} = 13.85$.



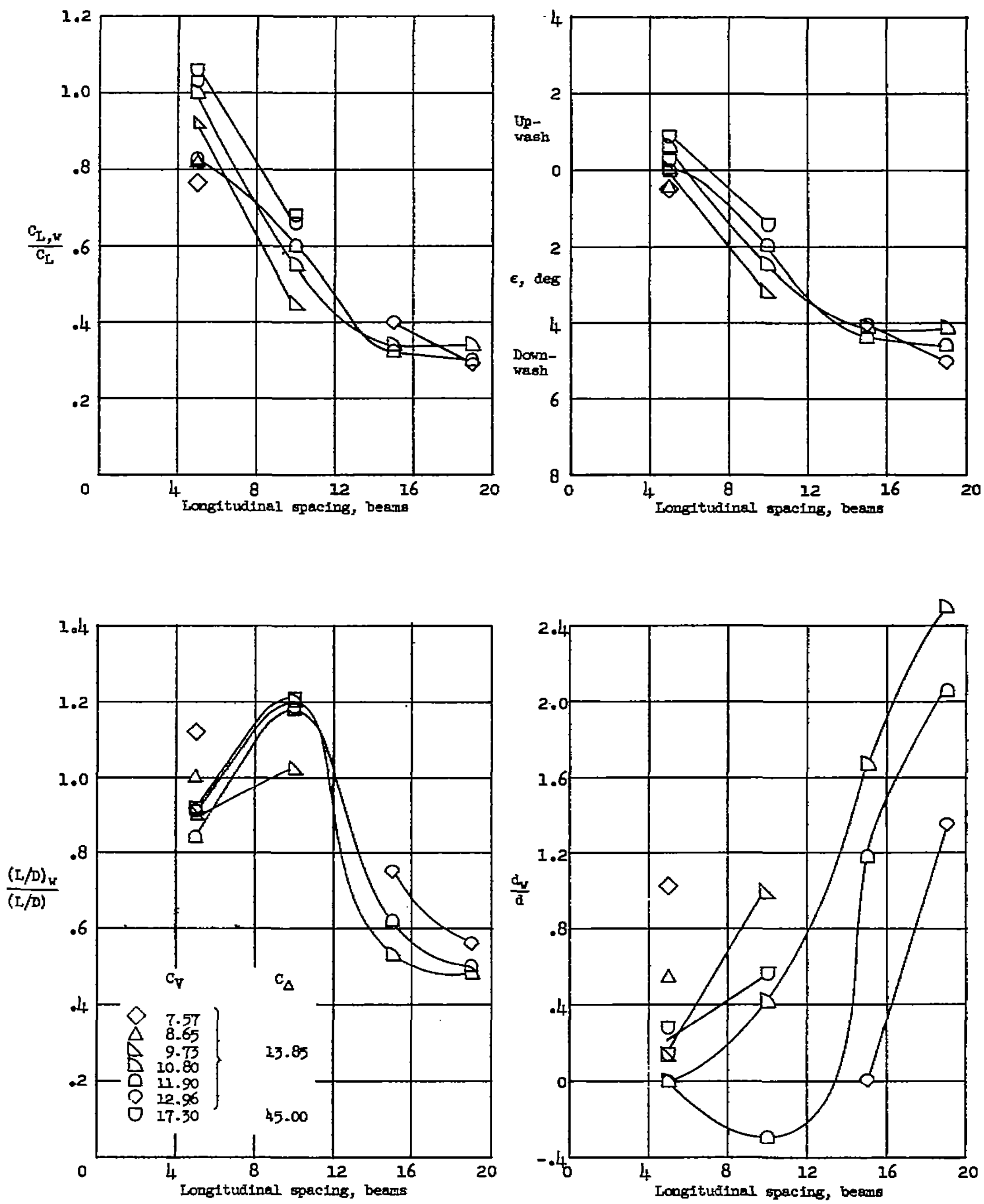
(a) Center-line spacing of rear hydro-skis, 3 beams.

Figure 6.- Data obtained with three-hydro-ski arrangement at $\alpha = 6^\circ$.



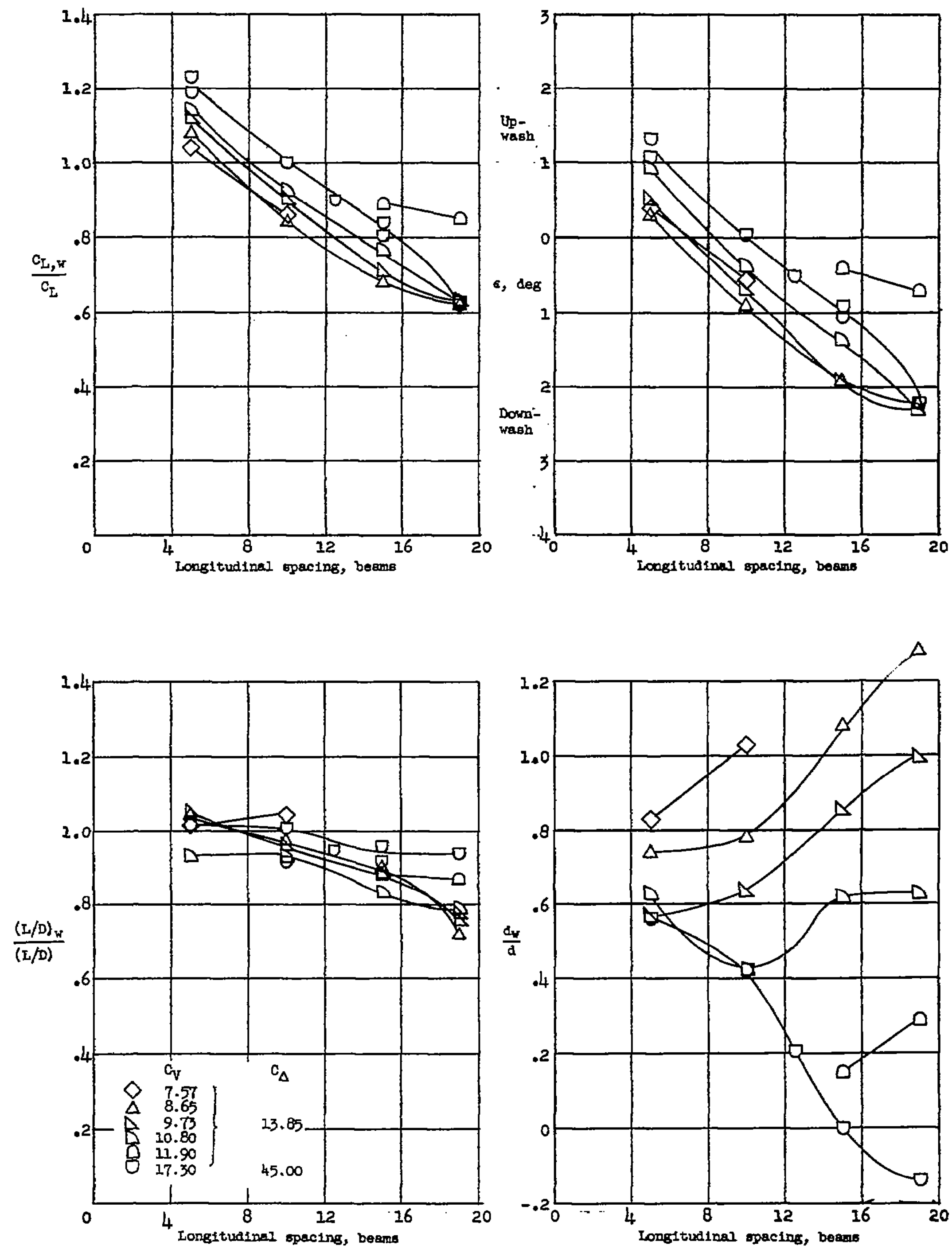
(b) Center-line spacing of rear hydro-skis, 5 beams.

Figure 6.- Concluded.



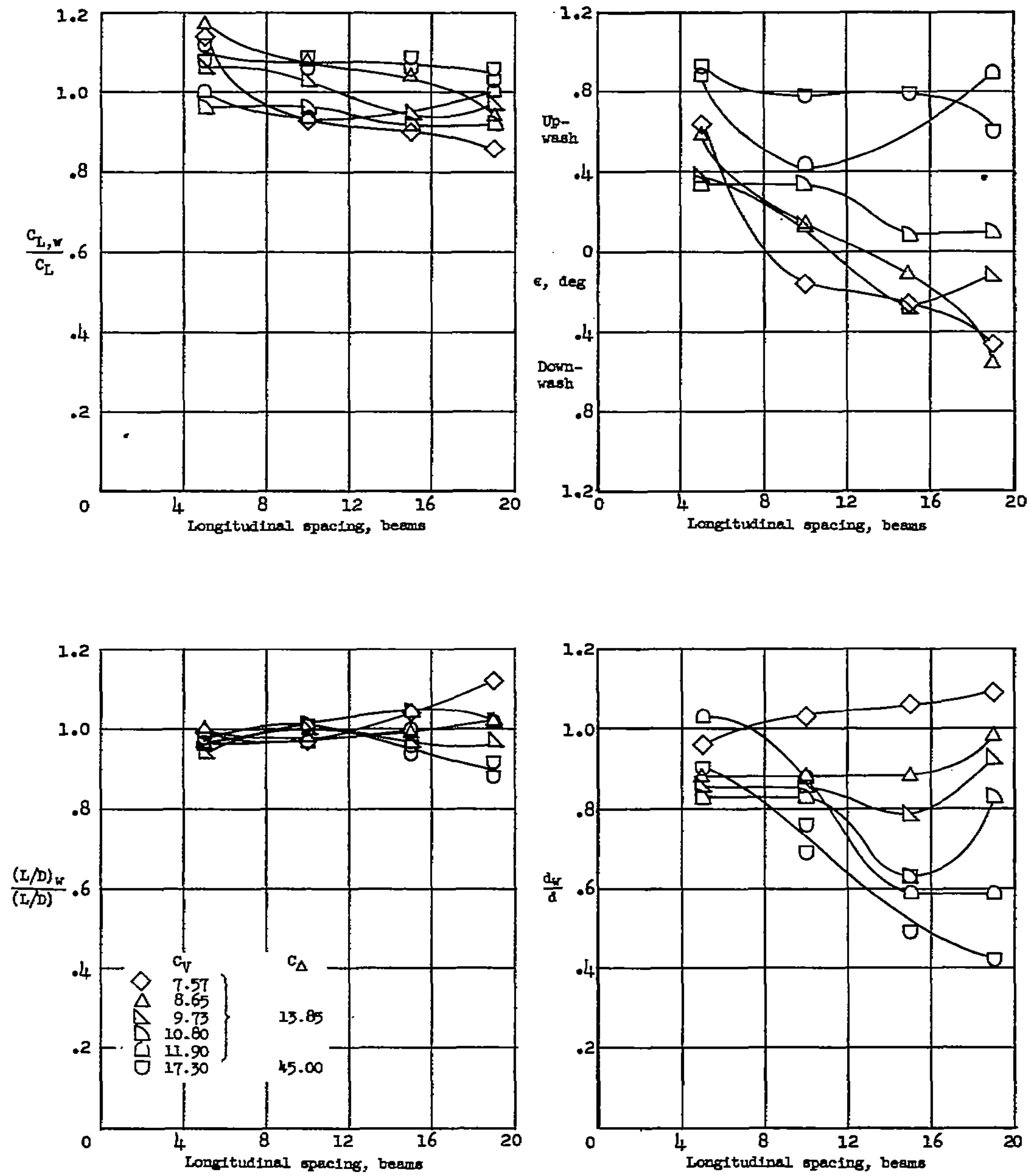
(a) Center-line spacing of rear hydro-skis, 3 beams.

Figure 7.- Data obtained with the three-hydro-ski arrangement at $\alpha = 12^\circ$.



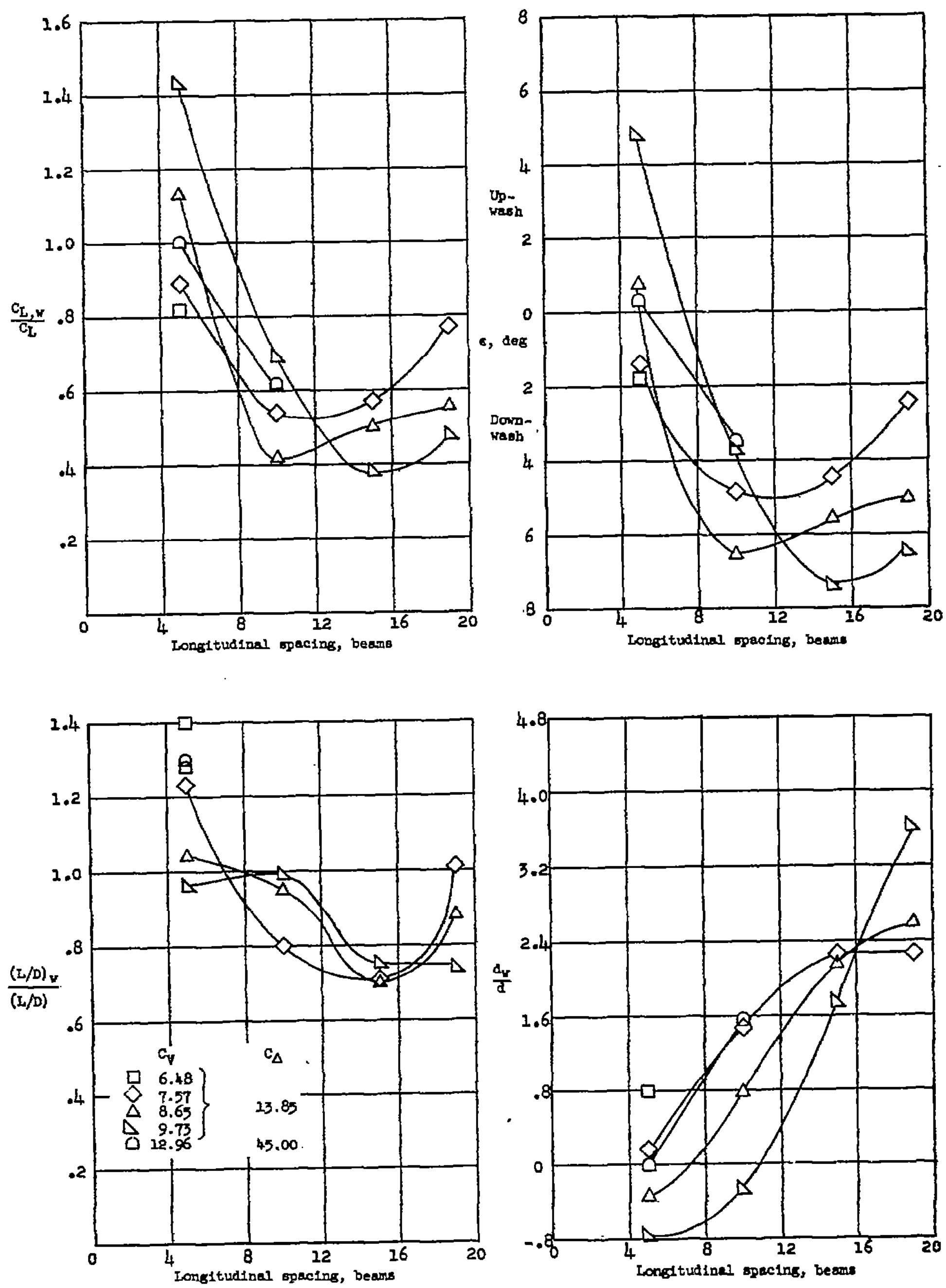
(b) Center-line spacing of rear hydro-skis, 5 beams.

Figure 7.- Continued.



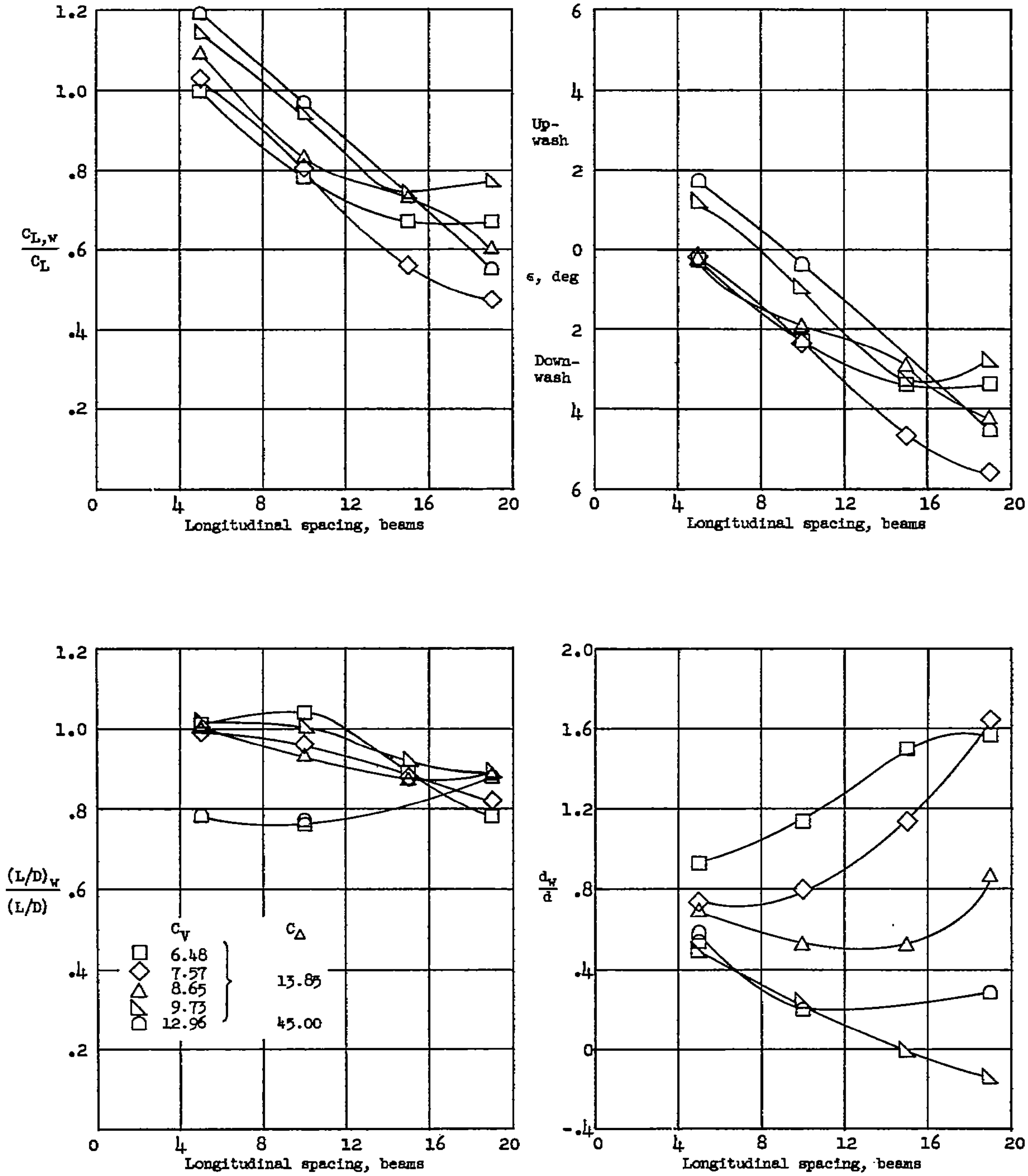
(c) Center-line spacing of rear hydro-skis, 7 beams.

Figure 7.- Concluded.



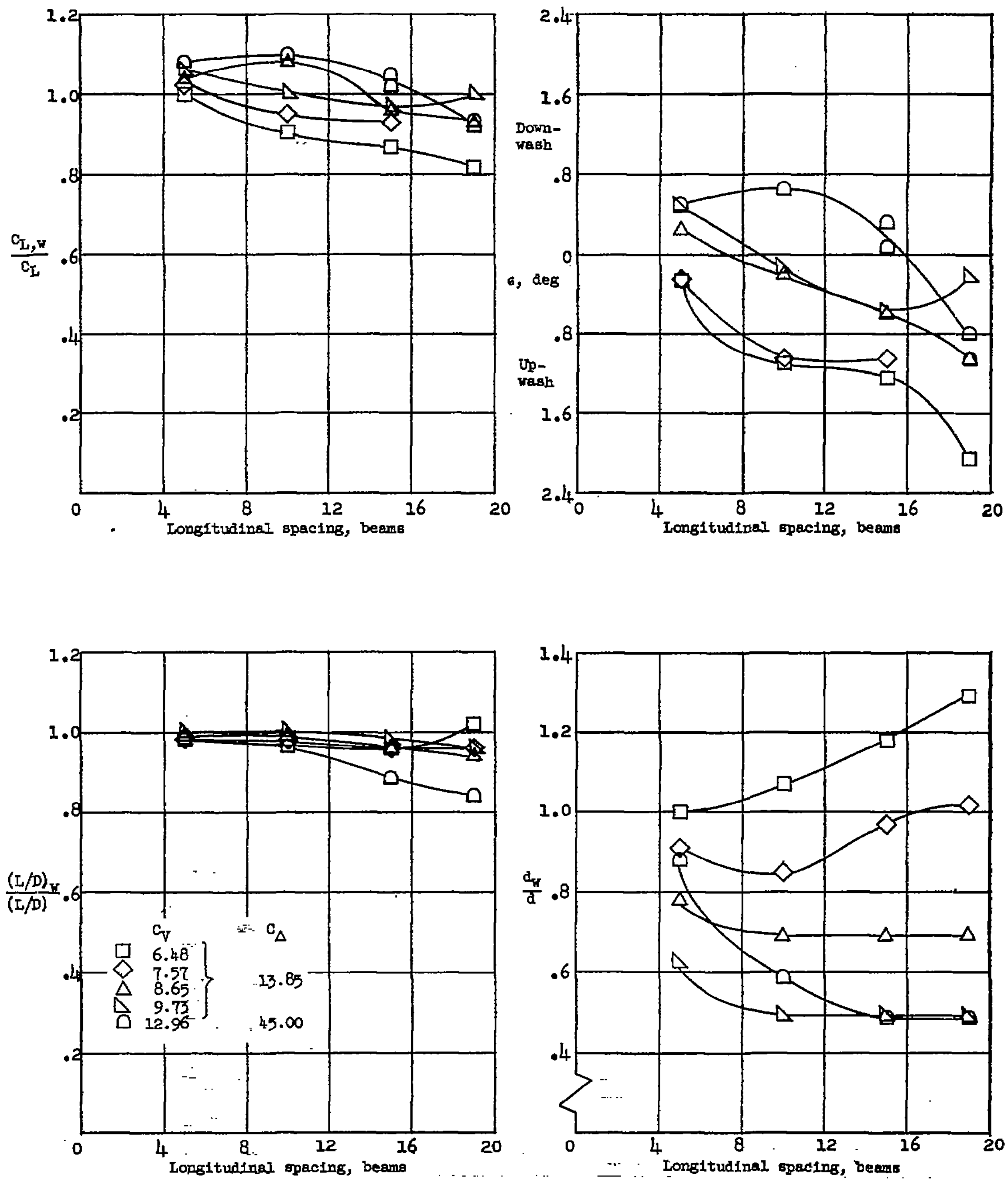
(a) Center-line spacing of rear hydro-skis, 3 beams.

Figure 8.- Data obtained with the three-hydro-ski arrangement at $\alpha = 18^\circ$.



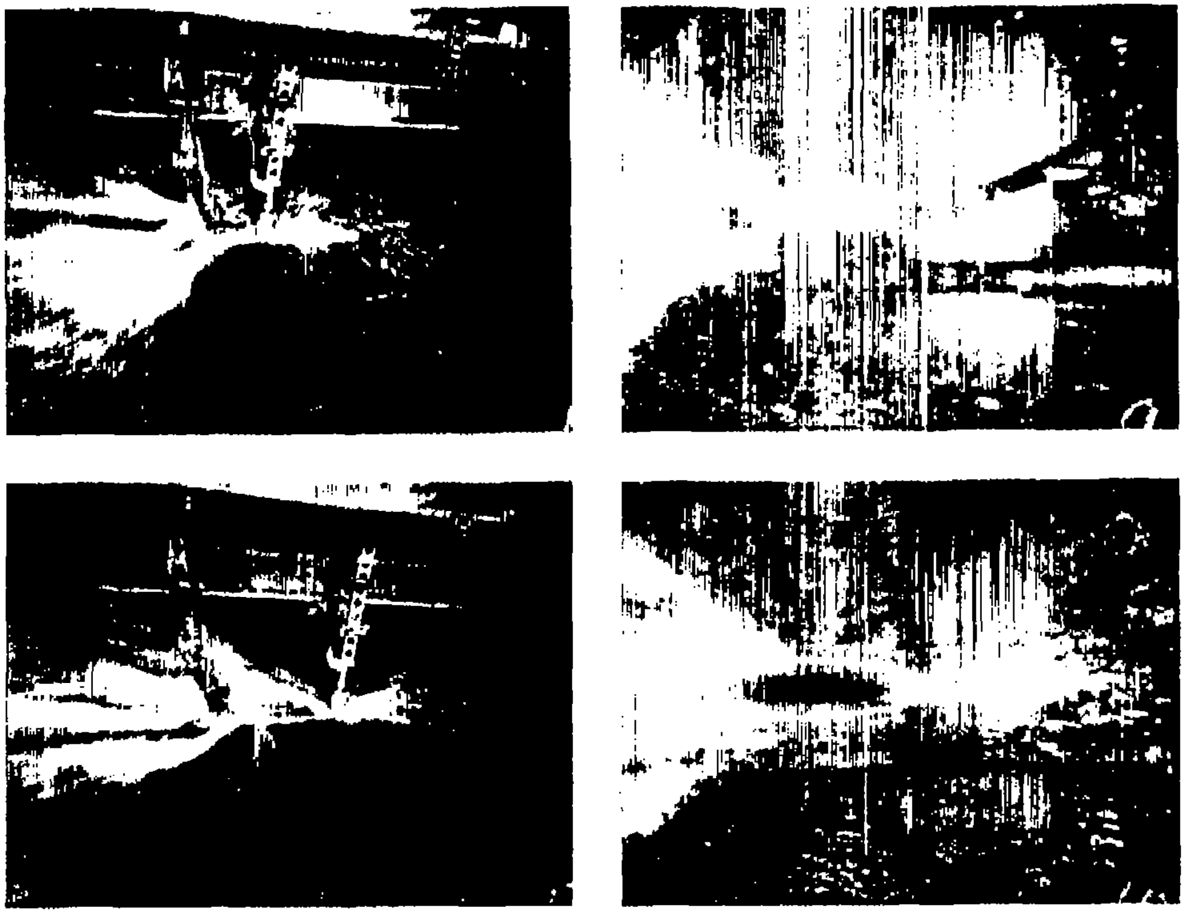
(b) Center-line spacing of rear hydro-skis, 5 beams.

Figure 8.- Continued.



(c) Center-line spacing of rear hydro-skis, 7 beams.

Figure 8.- Concluded.



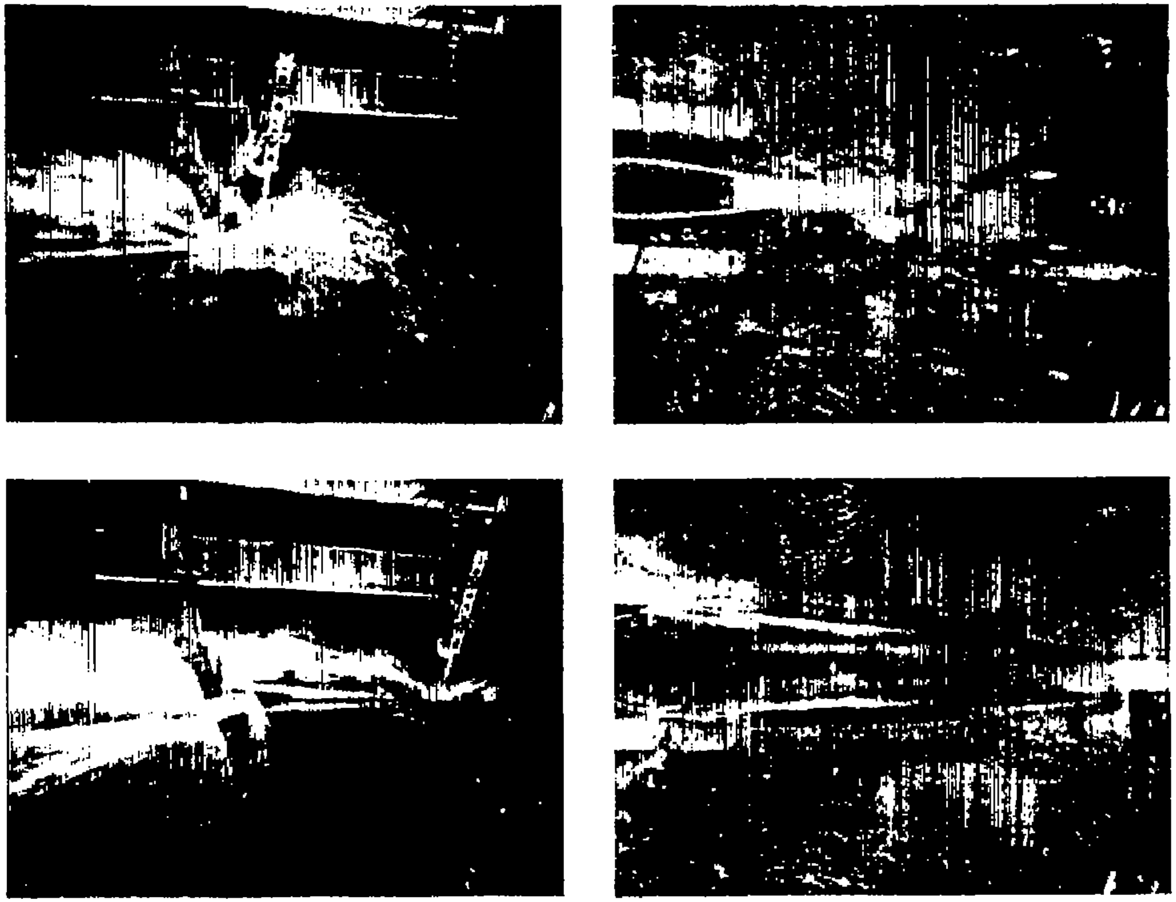
Longitudinal spacing = 5 beams; $\frac{C_{L,w}}{C_L} = 1.13$; $\frac{(L/D)_w}{(L/D)} = 1.04$.

Longitudinal spacing = 10 beams; $\frac{C_{L,w}}{C_L} = 0.42$; $\frac{(L/D)_w}{(L/D)} = 0.95$.

Side photographs Underwater photographs

(a) Center-line spacing of rear hydro-skis, 3 beams. L-58-129

Figure 9.- Sample photographs of the three-hydro-ski arrangement at $\alpha = 18^{\circ}$. $C_{\Delta} = 13.85$; $C_V = 8.65$.



Longitudinal spacing = 5 beams; $\frac{C_{L,w}}{C_L} = 1.09$; $\frac{(L/D)_w}{(L/D)} = 1.00$.

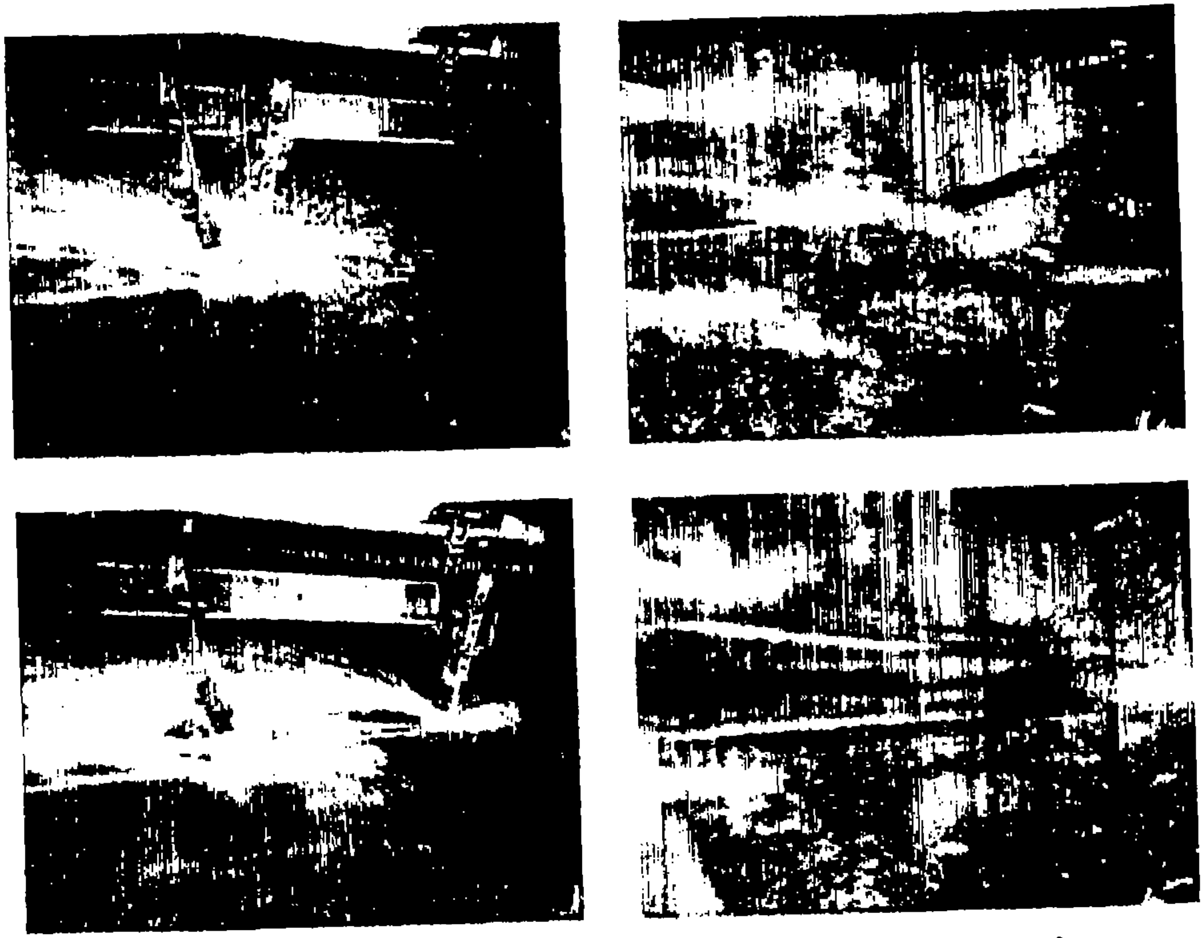
Longitudinal spacing = 19 beams; $\frac{C_{L,w}}{C_L} = 0.60$; $\frac{(L/D)_w}{(L/D)} = 0.88$.

Side photographs

Underwater photographs

(b) Center-line spacing of rear hydro-skis, 5 beams. L-58-130

Figure 9.- Continued.



Longitudinal spacing = 5 beams;

$\frac{C_{L,w}}{C_L} = 1.04;$

$\frac{(L/D)_w}{(L/D)} = 0.99.$

Longitudinal spacing = 19 beams;

$\frac{C_{L,w}}{C_L} = 0.93;$

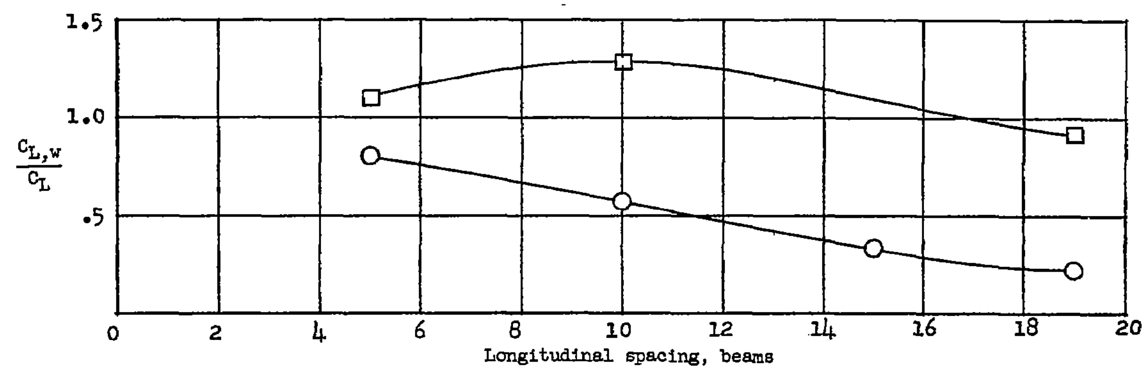
$\frac{(L/D)_w}{(L/D)} = 0.94.$

Side photographs

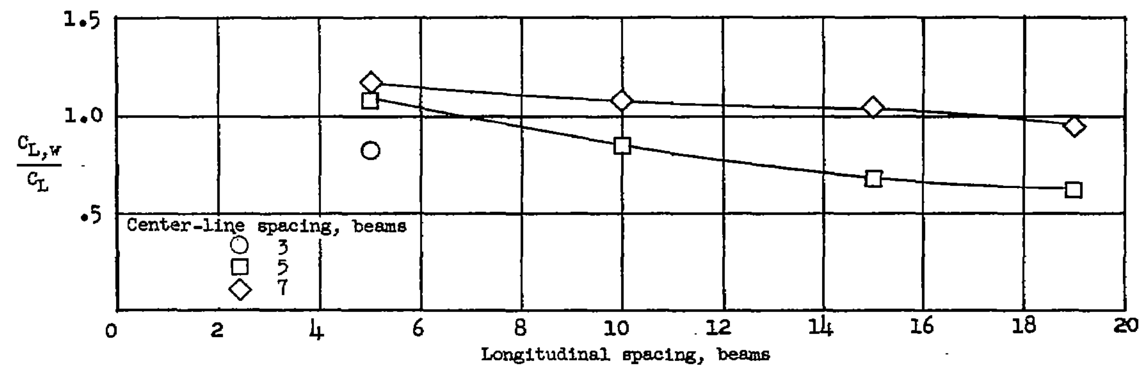
Underwater photographs

(c) Center-line spacing of rear hydro-skis, 7 beams. L-58-131

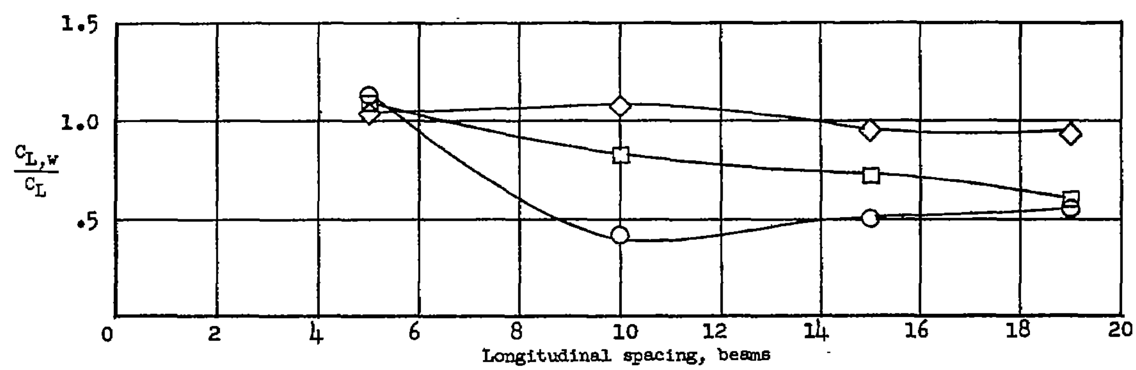
Figure 9.- Concluded.



(a) $\alpha = 6^{\circ}$; $C_V = 16.20$.



(b) $\alpha = 12^{\circ}$; $C_V = 8.65$.



(c) $\alpha = 18^{\circ}$; $C_V = 8.65$.

Figure 10.- Effect of hydro-ski spacing on three-hydro-ski arrangement. $C_{\Delta} = 13.85$.